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Tidal Analysis and Arrival Process Mining Using Automatic Identification System (AIS) Data

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Abstract

This work presents a method for extracting vessel arrival times and arrival processes from Automatic Identification System (AIS) data. This work employs the methodology presented by Mitchell and Scully (2014) for inferring tidal elevation at the time of vessel movement and calculating the tidal dependence (TD) parameter to 23 U.S. port areas for the years 2012–2014. Tidal prediction stations and observation reference lines are catalogued for considered ports. AIS data obtained from the U.S. Coast Guard, and 6-minute tide predictions, obtained from the National Oceanographic and Atmospheric Administration, are used to rank relative tidal dependence for arriving cargo and tank vessel traffic in studied locations. Results include relevant tide range and elevation threshold observations for each year and location studied. AIS-derived arrival processes, including arrival frequency, arrival rate, and interarrival time are visualized using several techniques with comparative discussion between ports to highlight implications for understanding seasonal traffic trends or port resiliency. The ports with the highest and lowest TD value, Portland, ME, and Los Angeles, CA, respectively, are discussed with regard to weekly arrival patterns and interarrival time. Cargo composition and value obtained through the Channel Portfolio Tool is also considered.

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Preface

This report was funded by the U.S. Army Corps of Engineers, Headquarters (HQUSACE), Project 454634, "Coastal Inlets Research Program" (CIRP). The CIRP is administered at the U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL), under the Navigation Research and Development (R&D) Program. Jeff E. McKee was HQUSACE Navigation Business Line Manager overseeing CIRP. W. Jeff Lillycrop (CHL) was the ERDC Technical Director of the Navigation R&D Program. Dr. Julie Rosati (CHL) was the CIRP Program Manager.

The work described in the report was performed under the Coastal Engineering Branch (HN-C) of the Navigation Division (HN), ERDC-CHL. At the time of publication, Tanya Beck was Branch Chief (HN-C), and Dr. Jackie Pettway was Division Chief (HN). Jeffrey R. Eckstein was Deputy Director of CHL, and José E. Sánchez was the Director of CHL.

COL Bryan S. Green was Commander of ERDC. Dr. Jeffery Holland was ERDC Director.

Unit Conversion Factors

Multiply	By	To Obtain
feet	0.3048	meters
knots	0.5144444	meters per second
knots	1.68781	feet per second

1 Introduction

Background

The U.S. Army Corps of Engineers (USACE) is responsible for planning, constructing, and maintaining a vast nation-wide network of navigation channel infrastructure in coastal and riverine systems. Environmental conditions vary widely across the network, specifically with regard to tidally driven water surface elevations. Tidal regimes include diurnal, semidiurnal, and mixed systems with virtually no tidally driven water surface changes (e.g., on the Great Lakes and inland rivers) to tidal ranges that approach 30 feet (ft) (e.g., parts of Alaska). Fluctuation of the water surface resulting from tide is significant at projects that experience the phenomenon. Vessel operators may take advantage of tidally driven water surface changes to sail with drafts larger than could otherwise be achieved without additional tidal height.

Recent examples of planning feasibility studies including harbor deepening at Savannah, GA, Charleston, SC, and the Port of New York and New Jersey, among others, demonstrate that each project considers the unique impacts of tidally varying depth when planning for project expansion. Despite the variety and importance of tidal fluctuations within the portfolio of navigation projects, a comprehensive evaluation of tidal influence across the network has not been undertaken. Possible reasons for the lack of a comprehensive evaluation include lack of access to data, lack of an objective and repeatable methodology, and the sheer scope of the problem.

Objective

The objective of this report is to capitalize on the emergence of Automatic Identification System (AIS) technology as a remote sensing tool for vessels operating within the USACE navigation project portfolio. Due to the expansive use of AIS by vessels within the coastal portion of the navigation portfolio, an opportunity exists to undertake an evaluation of navigating vessel behaviors, including those related to tidally driven water surface fluctuations, in a large sample of USACE projects.

Generally, AIS data cover most large commercial ships transiting coastal and inland navigation projects within the USACE portfolio. Coastal data

acquisition and dissemination is performed by the U.S. Coast Guard (USCG). AIS coverage for inland waterways is generally less robust than for coastal projects. Inland data coverage is expanding, with collection performed by the USACE. Once collected, data from inland regions are incorporated into the larger USCG data store. Scully and Mitchell (2015) provide insight into potential uses, interpretation, and availability of AIS data.

In the course of investigating the role of tide during vessel arrivals, it was further recognized that due to the nature of the tidal analysis performed in this study, arrival processes can be easily mined from AIS data as a byproduct of the tidal analysis information. Both tidal considerations and traffic volume and frequency estimation are identified in USACE engineering manuals as important navigation study inputs (USACE 2006). Vessel arrival processes, including arrival time, interarrival time, and arrival frequency are commonly used as inputs to USACE navigation feasibility study models. Arrival processes are normally derived from data after aggregating a variety of sources, including vessel pilot and terminal operations logs, into one dataset. The availability of a method that relies on AIS data allows for simplification and standardization.

This report is organized as follows. Chapter 2 describes the data that was used in this investigation and how data can be obtained. The methods for performing tidal analysis and determining vessel arrival processes are described in Chapter 3. Analysis results are presented in Chapter 4. Chapter 5 contains discussion of the results and their implications for waterway managers. Conclusions drawn from the investigation are presented in Chapter 6.

2 Data Description and Sources

This investigation relies on data from two primary sources. AIS data was requested manually in full resolution from the USCG via the agency's Nationwide AIS (NAIS) system. The NAIS system is designed to enhance maritime domain awareness within continental United States and territorial waters. Archived NAIS data are available from the program's historic data request page: www.navcen.uscg.gov/?pageName=dataRequest&dataRequest=aisHistoricalRequestForm. AIS data archives are also available from commercial vendors or may be collected with the use of an AIS receiver with archival capability. Water surface elevation information was requested automatically through the National Oceanographic and Atmospheric Administration (NOAA) tides and currents applications program interface (API): http://tidesandcurrents.noaa.gov/api/.

AIS data

AIS data formatting is specified by the International Telecommunication Union (ITU 2014). The data contained in position report messages include a time stamp, latitude, longitude, and course over ground. Message type 5 contains vessel particulars, including vessel and cargo type code. These four data dimensions were used in this study. The time stamp is provided in Coordinated Universal Time (UTC). Position information is provided relative to the World Geodetic Survey (WGS) 1984 datum. Time stamp and position information, both referred to as dynamic information, are automatically generated by electronic navigation systems onboard vessels using AIS technology. Position reports, contained in message types 1, 2, and 3, are generated at varying frequencies that depend on vessel behavior, ranging from 2 to 180 seconds (sec) as described in Table 2. The vessel and cargo type dimension, referred to as static since it changes very infrequently, is manually generated. This is a two-digit code, described in the ITU technical specification. Several authors, including the commonly cited work by Harati-Mokhtari et al. (2007), describe considerations that must be given to ensure AIS data quality is sufficient for specific use cases.

Water surface elevation data

NOAA predicts water surface elevation data at several frequencies for locations that are influenced by the tide. NOAA also collects water surface elevation information, which can be compared to predictions. This study

relied on water surface predictions generated at 6-minute (min) intervals for major stations within the ports of interest. Water surface elevation data is referenced to mean lower low water (MLLW) elevation datum, and prediction times are in UTC. Water surface predictions, instead of verified water surface elevations, are used for three general reasons. First, it is most likely that tide-reliant vessels planning transits will rely on predictions to plan transits, and verified information will be unavailable for planning. Second, verified information includes the effects of atmospheric and hydrologic influence that are most likely well beyond the ability of NOAA to predict accurately. Third, operational limitations including loss of tidal station measurement function may result in data gaps within the study period.

3 Methods

Scully and Mitchell (2013) and Mitchell and Scully (2014) outline a method for interpretation of water vessel surface elevation information at the time of vessel arrival. This technical report expands the level of detailed methodology provided by the authors.

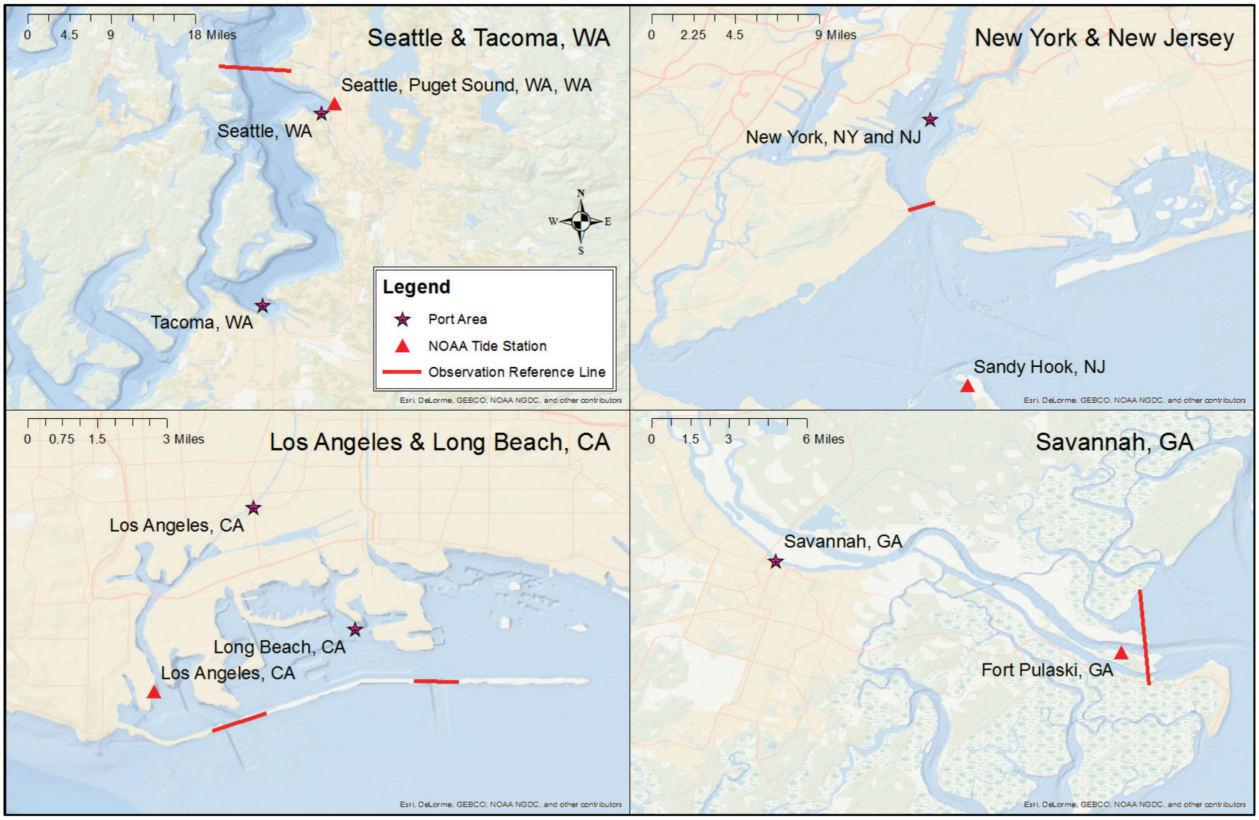
Observation location selection

A reference observation line is required to investigate tidal influence. A line crossing a waterway, defined by two latitude and longitude pairs, should be selected at the location of interest. This line will be used to count the number of vessels crossing the line and to document the time of vessel crossing. Both are key methodological inputs.

Observation reference lines should be carefully selected and based on known navigation channel locations. Alternatively, reference location selection may be made using geographical features such as coastal inlets or exploratory plotting of AIS data to identify vessel position report clusters. AIS information is carried over very high frequency (VHF) radio signals, which are limited to line-of-sight transmission. Geographical features, including bridges, valleys, dense urban structures, or anything conceivably capable of interfering with AIS transmission or reception, should be avoided when selecting reference locations. Sample reference lines and tidal stations used in this study are shown for Seattle and Tacoma, WA; New York and New Jersey; Los Angeles and Long Beach, CA; and Corpus Christi, TX, in Figure 1. A reference line for each port is shown in Appendix A.

Consideration should be given to the types of vessels that are likely to use the waterway being investigated. Reference lines should be selected to capture the vessel population of interest. Challenges may be encountered in locations with complex channel network components such as loops or branches. Locations with clustered terminals and short-range shipping routes may also require further assessment of reference selection.

Figure 1. Example tide station and reference line arrangement.



This study prioritized capture of the greatest fraction possible of large commercial vessel traffic by focusing on coastal inlets to port areas. The observation reference lines used in this study are listed in Table 1.

Table 1. Port areas, reference line coordinates, and NOAA (2013a) tide stations.

Port Area Entrance	Tide Station Number	Line Beginning Coordinate	Line Ending Coordinate
Anacortes, WA	9444900	(-122.7080, 48.4792)	(-122.7109, 48.5482)
Baltimore, MD	8574680	(-76.5651, 39.2375)	(-76.5493, 39.2562)
Boston, MA	8443970	(-71.0064, 42.3192)	(-71.0080, 42.3504)
Charleston, SC	8665530	(-79.8546, 32.7592)	(-79.8703, 32.7363)
Columbia River, OR	9439040	(-124.0860, 46.2644)	(-124.0750, 46.2331)
Delaware Bay, DE	8537121	(-75.4122, 39.2619)	(-75.3200, 39.3253)
Freeport, TX	8772447	(-95.2930, 28.9296)	(-95.2898, 28.9329)
Honolulu, HI	1612340	(-157.8656, 21.2955)	(-157.8741, 21.3020)
Jacksonville, FL	8720218	(-81.4214, 30.4094)	(-81.4216, 30.3976)
Long Beach, CA	9410660	(-118.1932, 33.7230)	(-118.1726, 33.7226)
Los Angeles, CA	9410660	(-118.2544, 33.7080)	(-118.2370, 33.7134)

Port Area Entrance	Tide Station Number	Line Beginning Coordinate	Line Ending Coordinate
Mobile, AL	8737048	(-88.0447, 30.6889)	(-88.0301, 30.6923)
New Haven, CT	8465705	(-72.9348, 41.2603)	(-72.9018, 41.2480)
New York and New Jersey	8531680	(-74.0554, 40.6036)	(-74.0348, 40.6096)
Norfolk, VA	8638610	(-76.3150, 36.9513)	(-76.3595, 37.0049)
Pascagoula, MS	8741533	(-88.5698, 30.3296)	(-88.5033, 30.3202)
Port Everglades, FL	8723214	(-80.1050, 26.0960)	(-80.1055, 26.0925)
Portland, ME	8418150	(-70.2390, 43.6662)	(-70.2238, 43.6521)
San Francisco Bay, CA	9414290	(-122.4770, 37.8094)	(-122.4800, 37.8268)
San Juan, PR	9755371	(-66.1361, 18.4718)	(-66.1234, 18.4708)
Savannah, GA	8670870	(-80.8863, 32.0150)	(-80.8913, 32.0684)
Seattle-Tacoma, WA	9447130	(-122.4064, 47.6535)	(-122.5190, 47.6602)
Tampa, FL	8726384	(-82.7348, 27.6224)	(-82.7394, 27.5337)

Interpret water surface threshold elevations

This study used high-, mid-, and low-tide segments of the tidal cycle (Scully and Mitchell 2013). High tide and low tide are defined as the upper and lower time-based quartile of water surface elevations, respectively. Mid-tide is defined as the time-based interquartile range of tidal elevations. Each year's record of predicted tidal elevation (87,600 predictions at 6 min intervals for a standard year) was ordered by elevation. The 25th quartile elevation is the threshold between low and mid tide and represents the elevation below which tidal elevations occurred 25% of the year. Similarly, the 75th quartile elevation is the threshold between mid and high tide and represents the elevation above which tidal elevations occurred 25% of the year. The mid tides occurred 50% of the year between the high and low thresholds. Thresholds for each location are determined independently for each of the years 2012, 2013, and 2014.

Vessel filtering, transit generation, and water surface at time of crossing

AIS data includes many dimensions for data filtering (ITU 2014; Scully and Mitchell 2015). Filtering for this study was applied to static and dynamic data components. Data were initially received from the USCG as a collection of 1-month-increment, comma-separated value files, organized by location. The data were processed using the Python programming language (van Rossum and Drake 2001), the Pandas data analysis package

(McKinney 2012), or the developmental version of USACE AIS Analysis Package (AISIAP) software.

Individual vessels are defined in this study as those having a unique Maritime Mobile Service Identifier (MMSI) number. Several authors have written about the potential complications of this approach (Harati-Mokhtari et al. 2007). By eliminating or verifying duplicate, vague, or incorrect MMSI numbers, most of these complications can be mitigated. For high-accuracy applications, comparing MMSI data to verified authoritative vessel information is recommended.

Vessels were filtered in this study based on the static “ship and cargo type” dimension, contained in Message 5 (again, subject to human error implications). Vessels with ship- and cargo-type codes that began with only “7” (cargo ships) or “8” (tankers) were included. Vessels were also filtered on the dynamic temporal, spatial, and heading dimensions, primarily derived from Messages 1, 2, or 3.

Vessels using Class A AIS transceivers report their position according to the reporting frequencies defined by the ITU (2014) and shown in Table 2. A simple approach for identifying unique transits is to identify gaps in the position report sequence that exceed normal report intervals.

Table 2. Class A AIS vessel reporting intervals (ITU 2014, Table 1).

Ship’s Dynamic Conditions	Nominal Reporting Interval
Ship at anchor or moored and not moving faster than 3 knots	3 min
Ship at anchor or moored and moving faster than 3 knots	10 sec
Ship 0–14 knots	10 sec
Ship 0–14 knots and changing course	3 1/3 sec
Ship 14–23 knots	6 sec
Ship 14–23 knots and changing course	2 sec
Ship > 23 knots	2 sec
Ship > 23 knots and changing course	2 sec

Transits were defined by identifying gaps in the position report sequence that exceed 360 sec (Scully and Mitchell 2013). This duration is chosen to ensure that vessels reporting their position at the lowest specified frequency (i.e., a “ship at anchor or moored and not moving faster than 3 knots”) will have at least one position identified if it is reporting normally and its signal

is unobstructed. These vessels are not generally of interest when assessing water surface elevation during transit. Ships moving with speed between 0 and 14 knots report at the next most frequent interval, one report every 10 sec. Vessels moving with speeds in this range will have ample position reports to construct a transit. Vessel reports that have been smoothed to a frequency lower than one report per 3 min will require a longer gap length or different transit generation method to reliably treat the data.

Vessel transits are limited by spatial filters. First, a 5,000 ft buffer was applied to either side of each observation reference line. Minimum bounding envelope geometry was applied to buffered areas to create regularly arranged rectangles for filtering. Vessels crossing each reference line are expected to transit on the order of 10,000 ft across the local study area.

The shortest report duration is specified as one report every 2 sec for vessels transiting at speeds greater than 23 knots. A vessel moving at 23 knots (38.8196 ft/sec) will sail 10,000 ft in approximately 258 sec and report its position approximately 129 times. This buffer distance ensures that transiting vessels among the population of interest will generate at least two position reports within each study area, ensuring transit generation.

Vessels were classified as either transiting inbound or outbound based on the heading data dimension. To facilitate this classification, an inbound direction vector was arbitrarily defined as being approximately normal to each observation reference line and pointing away from the open ocean and toward the port area of interest. Vessels were classified as inbound if the course over ground values of each transit were within +/- 90° of the cartographic direction of the inbound definition vector, and outbound otherwise. For example, if the inbound direction vector is defined to have a cartographic heading of 300°, then inbound vessels are those with course over ground ranging from 210° to 360° and from 0° to 30°. Only inbound vessels were included in this study.

To summarize the filtering scheme, only unique tanker and cargo vessels (based on unique identifying information and ship and cargo type code contained in AIS), heading away from the open ocean and toward selected ports (based on AIS embedded course over ground information) were considered. Vessels were selected from conservative buffer regions around

observation reference lines chosen to capture deep-draft vessel traffic. Analysis was performed for each location discretely in 2012, 2013, and 2014. Aside from this filtering, data were not thoroughly controlled for quality owing to the large quantity of data. This induces the risk that a fraction of the vessel population is missing or incorrectly classified within the AIS record. In all, over 120,000 vessel transits were generated to assess tidal influence.

Linear interpolation is used to determine the time at which vessels cross observation reference lines. The nearest position report to either side of the reference line is selected, and the time difference between reports is calculated. The distance between these two positions, and the distance from the earlier position report to the observation reference line, are also determined. The vessel-crossing offset is computed as the proportion of the reference line distance to the total distance. The offset is then multiplied by the time difference between position reports and added to the time of the earlier position report, yielding the time of vessel crossing.

Interpret water surface elevation at time of vessel crossing

The water level at the time each vessel crossed a reference line is linearly interpolated from the water level record using the time of vessel crossing and assigned to that transit. Vessels in transit generally move faster laterally than the tide can rise or fall over short periods of time. The most extreme tides in the world, at the Bay of Fundy, have been documented to experience changes in water surface elevation of 56 ft in approximately 12.42 hours (hr) (NOAA 2013b). The water surface elevation changes at a rate of 1.3×10^{-3} ft/sec (7.4×10^{-4} knots). A vessel reporting its position every 3 min would observe a change in water surface elevation of approximately 0.3 ft at that location. Since most vessels of interest to this study report their position every 10 sec, and the tidal variations at study locations are much less than the example (Seattle had the greatest tidal range at 16.71 ft), it is assumed the resulting errors in water surface elevation at time of vessel crossing are negligible.

It was further assumed that errors in water surface interpolation resulting from hydraulic friction loss over the distance between prediction location and observation location were negligible. For instance, the tidal prediction station at the port of Anacortes, WA, provides high- and low-tide predictions, based on the harmonic tidal observing station 9444900 at Port Townshend, WA, but does not provide 6 min water level predictions.

The Port Townshend station is approximately 28 miles from the observation line used to analyze Anacortes traffic. The Anacortes prediction station provides a time and elevation offset to the harmonic station. High tides at the Anacortes are predicted to occur 22 min later than at Port Townshend, and the tidal height is approximately 96% of the high-tide height. Low tide occurs approximately 33 min later at Anacortes than Port Townshend, and the low-tide heights are approximately equal.

The difference in high-tide height between Anacortes and Port Townshend is less than 6 inches (in.), or 3.9% of the observed tidal range. The diurnal tide range for Port Townshend is 9 ft, and the tidal period is approximately 12.42 hr, meaning a normal tide celerity of 0.72 ft per hr. A 33 min lag would result in approximately 5 in. in tide differential. The combined tide height and time lag errors amount to approximately 1 ft of the observed average tide range of 12.98 ft, which amounts to approximately 7.7% error. Because the observation reference line for Anacortes is closer to the Port Townshend harmonic station than the Anacortes prediction station, it can be expected that induced errors will be smaller.

Calculate tide sector traffic percentages and tidal dependence metric

After assigning the water level to each observed transit, compare water level transits to tide thresholds to apportion traffic to tidal cycle segments. The proportion of vessels assigned water surface elevations below the low-tide threshold is T_{25}. The proportion of vessels transiting above the high-tide threshold is T_{75}. T_{50}, the portion of traffic transiting during mid-tide, can be calculated as 1 - (T_{25} +T_{75}).

The tidal dependence (TD) metric (Mitchell and Scully 2014) is calculated as

$$TD = \left(T_{75} - T_{25}\right) / T_{50} \qquad (1)$$

The refined tidal dependence metric is intuitive. It is formulated such that vessel traffic uniformly distributed across the tidal cycle will result in a TD value of unity. Traffic regimes with dominant high-tide traffic will result in positive TD values whereas low-tide dominated ports will be negative. Mid-tide traffic acts to scale the value—as the mid-tide proportion of transits increases the TD parameter approaches zero. As the mid-tide proportion of transits decreases, the balance of high-tide vs. low-tide traffic becomes more

apparent, driving the value toward +/- ∞ asymptotically until the mid-tide portion equals 0.

Arrival process mining

Linear interpolation of the time of vessel arrival was demonstrated for single vessels in the previous section “Vessel filtering, transit generation, and water surface at time of crossing.” The time of vessel arrival is a critical input to port feasibility studies and is a fundamental input to arrival rate and interarrival process mining. Vessel arrival time is a required input to models that seek to quantify the impacts to changes in navigation infrastructure. Aggregating individual arrival times for a vessel population at the reach or port level results in the arrival frequency distribution of the navigation feature, which describes larger operations.

Arrival processes of general interest to USACE navigation planners and operators alike include the arrival rate and the interarrival time of vessels calling in a port or reach. The arrival rate is a measure of vessel arrivals per unit time. This measure is derived by dividing the number of arrivals by the unit time of interest. Vessels per day or month are commonly used as benchmark indicators of vessel activity. Long-term averages of vessel arrival rates can be compared to short-term arrival rates to identify peaks and lulls in vessel activity. Interarrival time is calculated by ordering vessel arrivals chronologically and calculating the time between arrivals to find the distribution.

4 Results

The methods described in the preceding section facilitate tidal analysis and arrival process extraction between geographically separated locations with differing tidal patterns. Table 3 summarizes the overall description of investigated port areas and includes the distance from tide stations to observation lines and observed tidal patterns. Values averaged over the years 2012, 2013, and 2014 include mean threshold elevations, tidal range, and the number of arriving vessels included in the analysis.

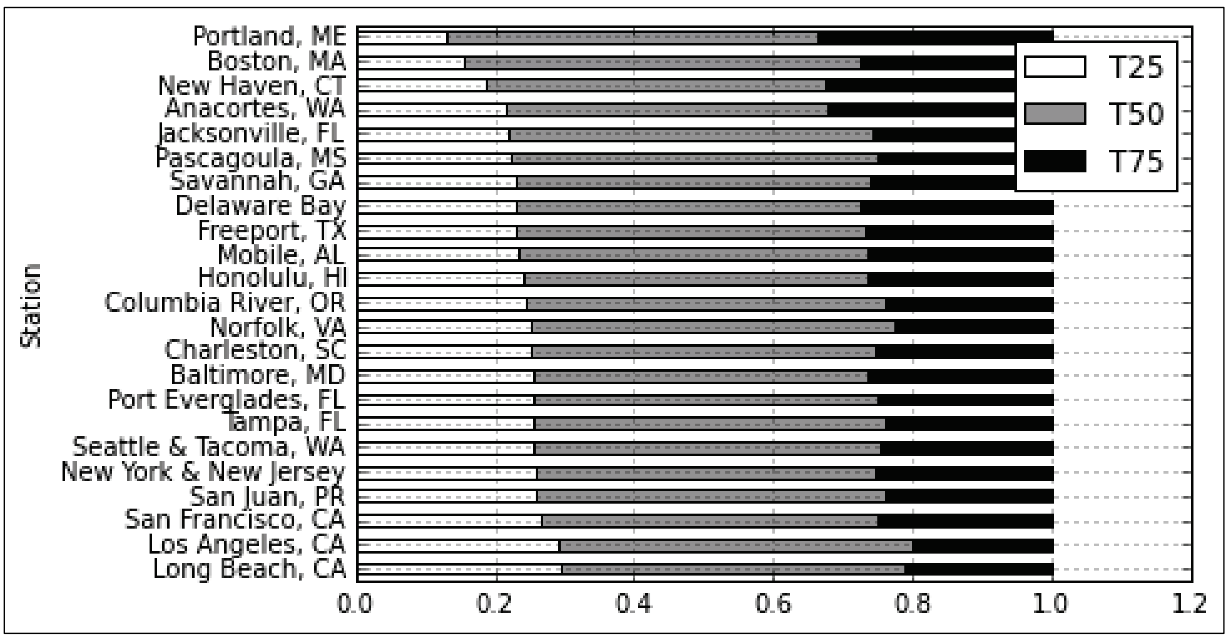
Table 3. Port area tidal information.

Port Area Entrance	Distance from Tide Station (miles)	Tidal Pattern	Mean 25th Percentile Elevation (ft)	Mean 75th Percentile Elevation (ft)	Avg. Tide Range (ft)	Avg. Number. Arriving Vessels
Anacortes, WA	28.2	mixed	3.19	7.05	12.98	473
Baltimore, MD	1.8	semi-diurnal	0.43	1.16	2.71	953
Boston, MA	2.8	semi-diurnal	1.99	8.41	14.43	719
Charleston, SC	4.3	semi-diurnal	1.11	4.69	8.29	1978
Columbia River, OR	15.3	mixed	2.43	6.73	12.53	1572
Delaware Bay, DE	2.8	semi-diurnal	1.07	4.92	8.86	2161
Freeport, TX	1.1	mixed	0.60	1.37	3.12	797
Honolulu, HI	0.7	mixed	0.36	1.25	3.11	1014
Jacksonville, FL	0.7	semi-diurnal	0.94	4.02	7.50	1541
Long Beach, CA	5.1	mixed	1.69	3.99	8.88	2003
Los Angeles, CA	1.6	mixed	1.69	3.99	8.88	2320
Mobile, AL	1.3	diurnal	0.43	1.20	2.98	690
New Haven, CT	2.1	semi-diurnal	1.26	5.37	9.13	138
New York and New Jersey	9.8	semi-diurnal	1.03	4.11	7.78	4608
Norfolk, VA	2.3	semi-diurnal	0.52	2.17	4.11	3989
Pascagoula, MS	3.3	diurnal	0.36	1.14	3.00	764
Port Everglades, FL	25.1	semi-diurnal	0.44	1.76	3.66	3083
Portland, ME	0.7	semi-diurnal	1.75	8.11	13.84	269
San Francisco Bay, CA	1.1	mixed	1.87	4.48	8.94	3143
San Juan, PR	1.2	mixed	0.41	1.12	2.62	1233
Savannah, GA	0.8	semi-diurnal	1.49	6.12	10.48	2471
Seattle-Tacoma, WA	6.8	mixed	4.30	9.36	16.71	1821
Tampa, FL	11.6	mixed	0.71	1.64	3.75	1007

Tidal analysis

Figure 2 shows the average of 2012, 2013, and 2014 tidal segment traffic percentages for each studied port, ordered by increasing low-tide traffic percentage. Portland, ME, had the greatest percentage of vessel traffic, 33.5%, moving above the high-tide threshold. New Haven, CT, and Anacortes, WA, stand out as having a relatively high portion of high-tide traffic. Los Angeles, CA, had the lowest percentage of vessel traffic, 20.1%, transiting above the high-tide threshold. Los Angeles, CA, and Long Beach, CA, both stand out as having a relatively high proportion (29%) of traffic arriving below the low-tide threshold. Portland had the lowest fraction of traffic arriving below the low-tide threshold, at 13%.

Figure 2. Average 2012–2014 low-, high-, and mid-tide traffic distributions.



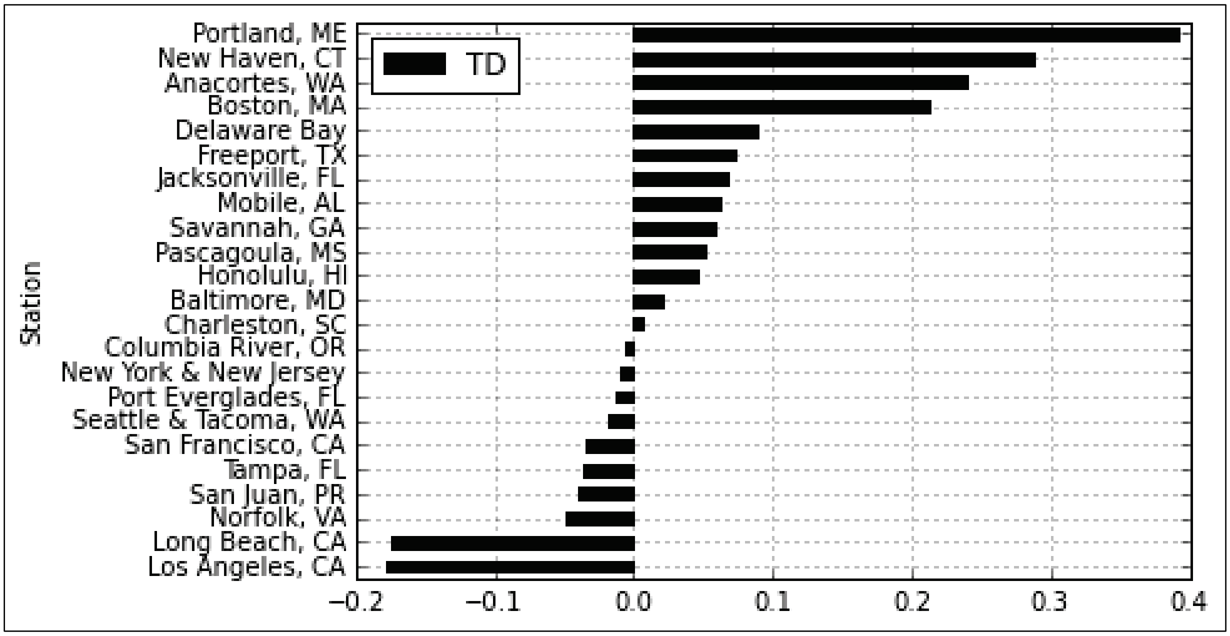
Average traffic percentages and TD values are summarized for each port in Table 4. The fraction of traffic moving on the ends of the tidal range for Portland, ME, is 46%, compared to Los Angeles, which is 49%. While these two ports show the greatest tidal imbalances, they are not the ports with the greatest fraction of traffic moving above or below the respective high- and low-tide thresholds. Anacortes saw the highest proportion of traffic, at 54%, move outside of mid-tide. Boston saw the lowest fraction of traffic moving outside of mid-tide, at 43%. The variable range of traffic in point terms was similar for all segments: 16 for low tide, 11 for mid tide, and 13 for high tide.

Table 4. Average 2012–2014 T_{25}, T_{50}, T_{75}, and TD values.

Port Area Entrance	T_{25} (mean)	T_{50} (mean)	T_{75} (mean)	TD (mean)
Anacortes, WA	0.22	0.46	0.32	0.24
Baltimore, MD	0.25	0.48	0.26	0.02
Boston, MA	0.16	0.57	0.28	0.21
Charleston, SC	0.25	0.49	0.26	0.01
Columbia River, OR	0.25	0.53	0.23	-0.01
Delaware Bay, DE	0.23	0.50	0.27	0.10
Freeport, TX	0.23	0.50	0.27	0.07
Honolulu, HI	0.24	0.50	0.26	0.05
Jacksonville, FL	0.22	0.52	0.26	0.07
Long Beach, CA	0.29	0.50	0.21	-0.17
Los Angeles, CA	0.29	0.51	0.20	-0.18
Mobile, AL	0.23	0.50	0.26	0.06
New Haven, CT	0.19	0.49	0.33	0.29
New York and New Jersey	0.26	0.49	0.25	-0.01
Norfolk, VA	0.25	0.52	0.23	-0.05
Pascagoula, MS	0.22	0.53	0.25	0.05
Port Everglades, FL	0.26	0.50	0.25	-0.01
Portland, ME	0.13	0.53	0.33	0.39
San Francisco Bay, CA	0.27	0.49	0.25	-0.03
San Juan, PR	0.26	0.50	0.24	-0.04
Savannah, GA	0.23	0.51	0.26	0.06
Seattle-Tacoma, WA	0.26	0.50	0.25	-0.02
Tampa, FL	0.26	0.51	0.24	-0.04

Figure 3 shows the TD value of each port in descending order. This plot can be interpreted to identify where preference for traffic moving in a particular tide segment exists. Portland traffic can be said to demonstrate a preference for high tide whereas Los Angeles can be said to exhibit low-tide preference. Charleston, SC, and Columbia River, OR, can be said to show weak tidal preference. It is interesting to note that Boston and Anacortes, the ports with the least and most traffic moving in any tidal segment, respectively, both show a relatively high preference for high-tide transits.

Figure 3. Average (2012-2014) TD value for inbound cargo and tanker vessels.



Arrival processes

The number of vessels arriving at each port per day, calculated as the total number of observed arrivals per year divided by the number of days in that year, provides an indication of potential traffic congestion within the port. Arrival process mining from AIS data results in the arrival rates displayed in Figure 4. The majority of studied ports have fewer than 10 vessel arrivals per day. New York and New Jersey had the highest arrival rate with an average of 12.6 vessels per day. New Haven had the lowest arrival rate (0.4 arrivals per day). The ports of Los Angeles and Long Beach had a combined arrival rate of 11.9 vessels per day, ranking it as the second busiest port area in the study, ahead of Norfolk with a rate of 10.9 arrivals per day.

Figure 4. Daily arrivals at studied ports, 2012-2014.

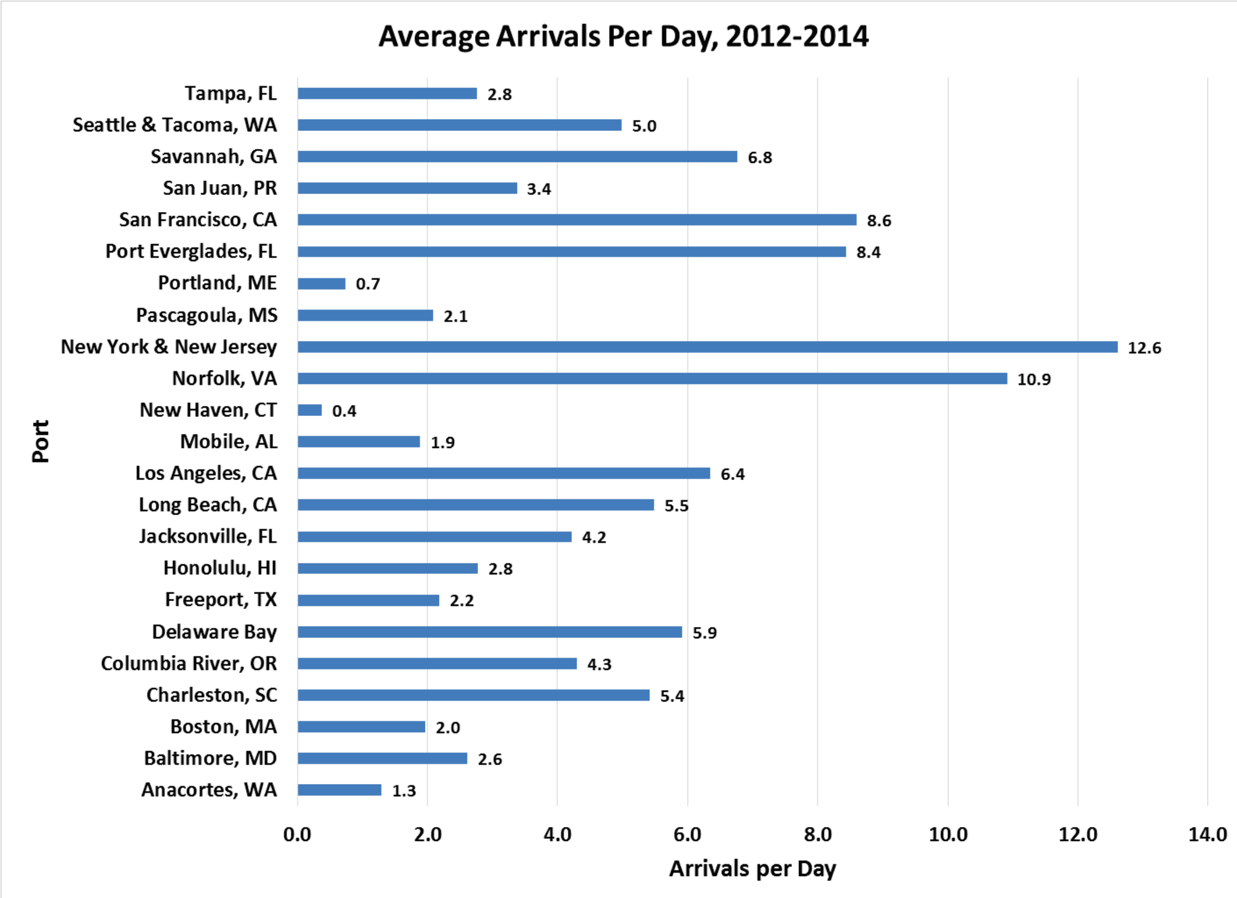
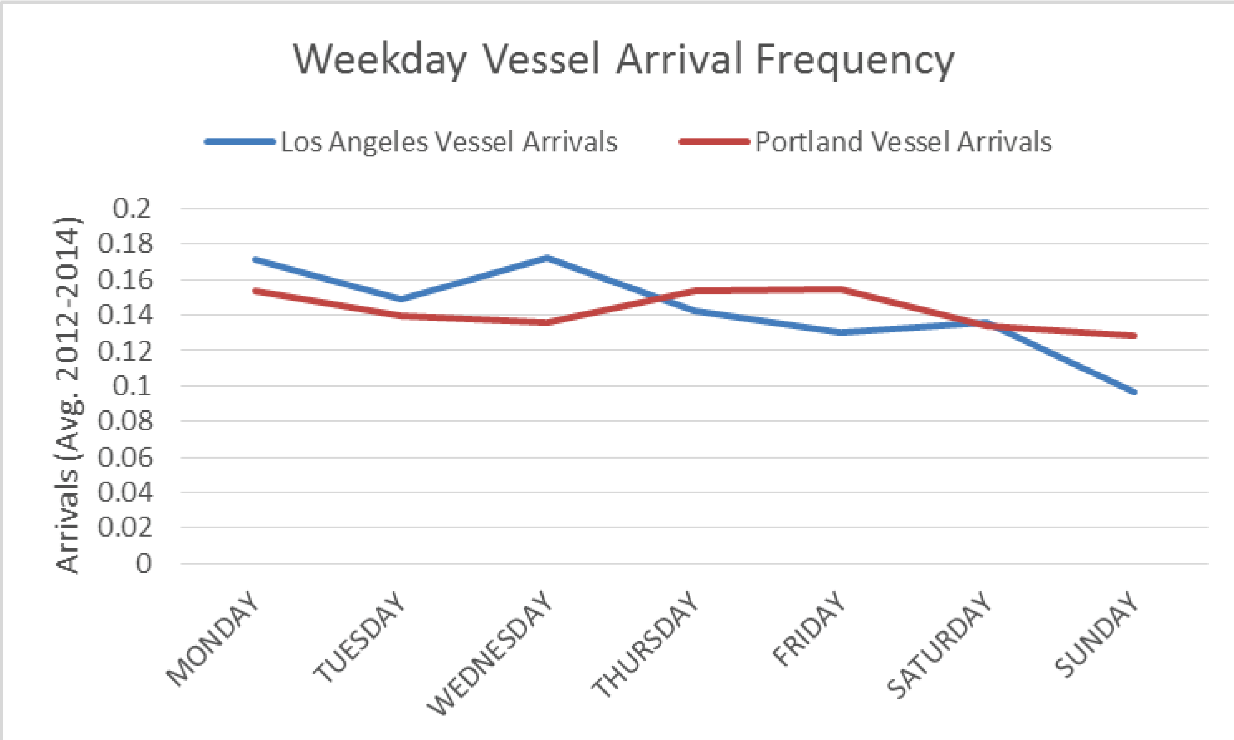


Figure 5 shows the relative percentage of vessel arrivals per day of the week at Los Angeles, CA, and Portland, ME, the two most tidally influenced ports identified through this analysis. The frequency distributions are similar, generally declining from Monday through Sunday. This observation was common in many ports and suggests that the previous arrivals-per-day measure under-reports arrivals Monday through Friday and over-reports arrivals on Saturday and Sunday. Los Angeles traffic was observed to peak on Monday and Wednesday with 17% of traffic arriving each of those days. Portland traffic was observed to arrive with peak frequencies on Monday, Thursday, and Friday, each with approximately 15% of traffic on each of those days. The least frequent arrival day in both cases was Sunday, with arrivals of 10% and 13% of traffic arriving that day in Los Angeles and Portland, respectively.

Figure 5. Vessel arrival frequencies are similarly distributed at Los Angeles, CA, and Portland, ME.



Greater detail of vessel arrival patterns is available from the AIS-derived vessel arrival data. Figure 6 shows the number of vessels observed to arrive at the ports of Los Angeles, CA, and Portland, ME, in 2012 by day of the week and hour of the day. It is evident from this mapping that seemingly similar traffic distributions have very different daily patterns. Portland demonstrates weak clustering of vessel arrivals whereas Los Angeles demonstrates strong arrival clusters Monday through Saturday, centered around 1200 (UTC) and 2200 (UTC).

Figure 7 shows the interarrival times for cargo and tanker vessels calling at Los Angeles, CA, and Portland, ME, binned in 1 hr increments. The time between arrivals at Los Angeles follows a negative exponential distribution. Fully 35% of arrivals at Los Angeles are followed by another arrival within 1 hr. These arrival processes can be informative when drawing conclusions or making decisions related to vessel traffic within a port. For instance, interarrival time distributions may be used to inform discussions regarding the time required to recover from traffic disruptions.

Figure 6. Daily vessel arrivals by hour for Portland and Los Angeles, 2012.

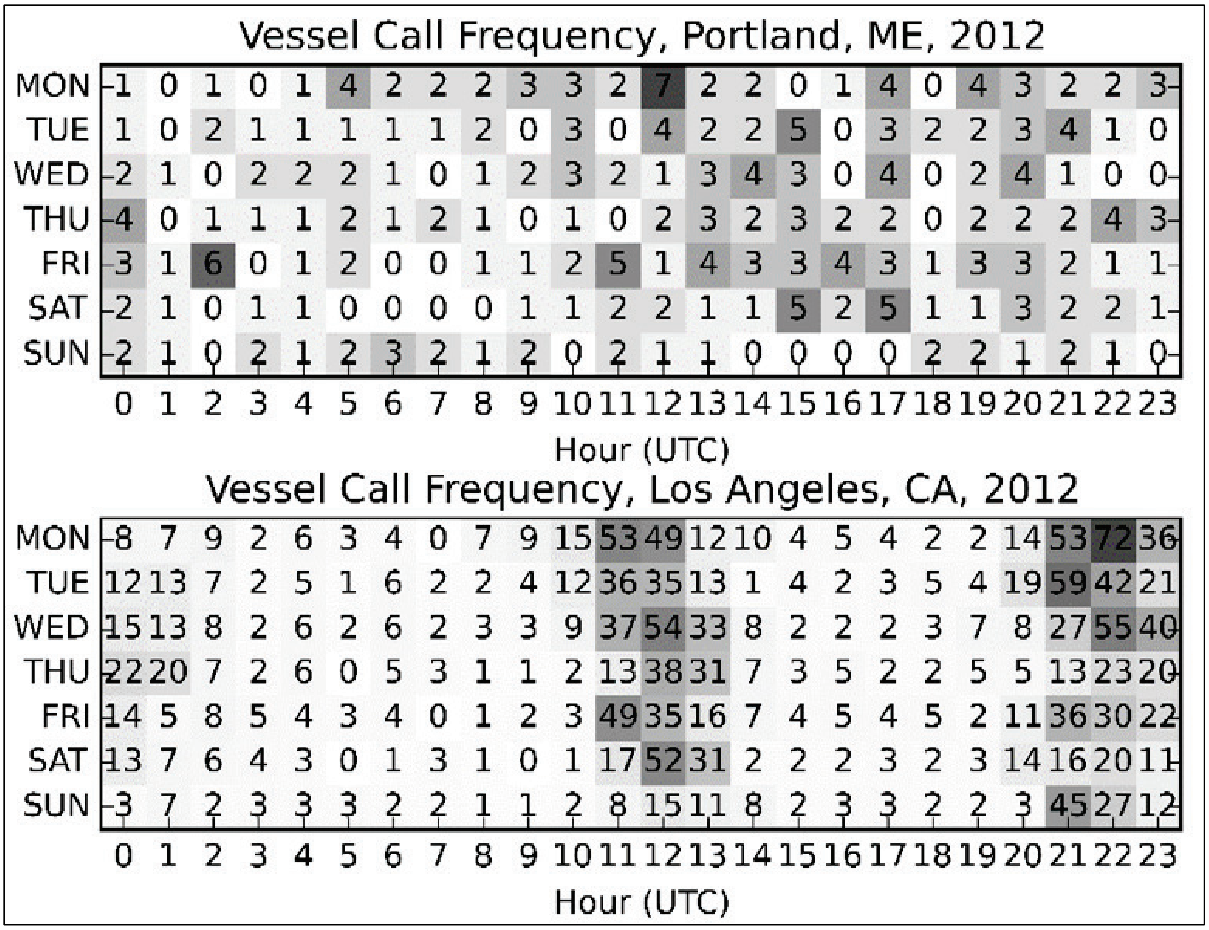
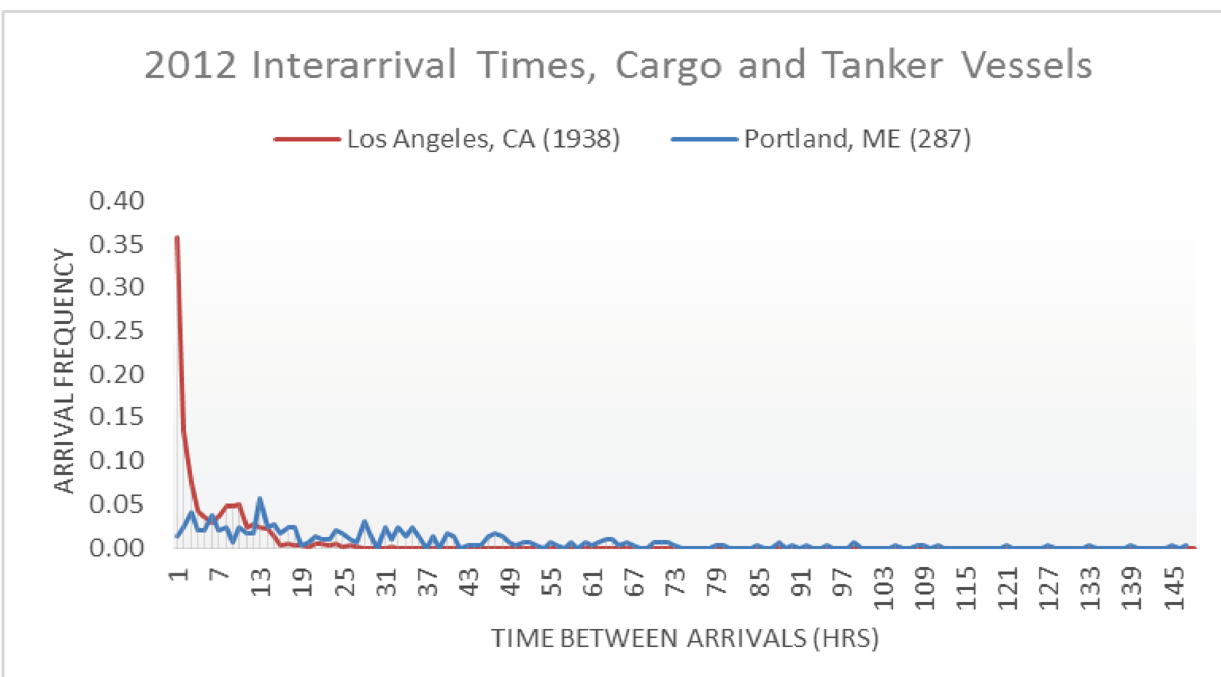


Figure 7. Interarrival times show differing levels of congestion at Los Angeles, CA, and Portland, ME, in 2012.



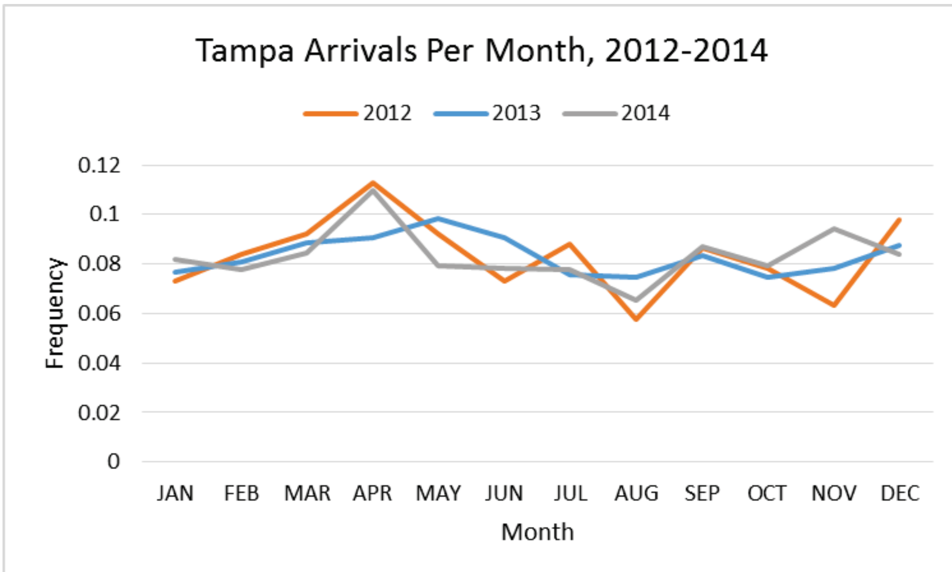
Monthly arrival rates can be mined from AIS data to help identify larger traffic patterns if they exist within a port. For example, this analysis of AIS data suggests a spring peak in vessel arrivals in Tampa in 2012–2014, shown in Figure 8(a), and a summer peak in arrivals in the Columbia River in 2012 and 2013, shown in Figure 8(b). The frequency range of monthly arrivals may serve as a metric for variability of port traffic. The Columbia River had the greatest range of arrival frequency (13.3%), while Seattle and Tacoma, shown in Figure 8(c), had the narrowest range (2.0%).

A complete set of results for each port is provided in Appendix A. Results for each port include

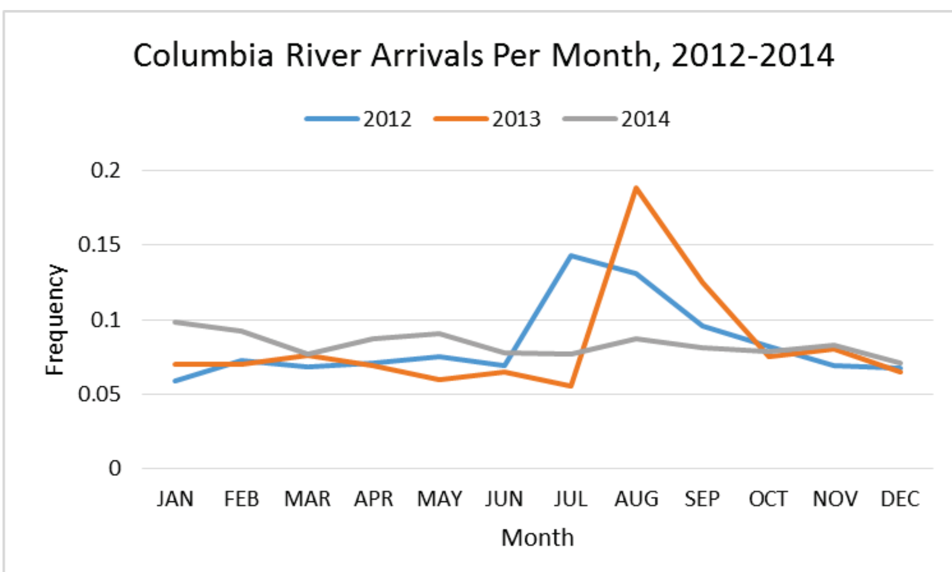
- general arrangement of the tide station and observation reference line
- tidal station information
- yearly summary for water surface thresholds and observed tidal range
- yearly summary for number of vessel arrivals, vessel interarrival time, and arrival frequency
- yearly summary for tide segment traffic percentages
- yearly distributions of vessel arrival by water surface elevation.

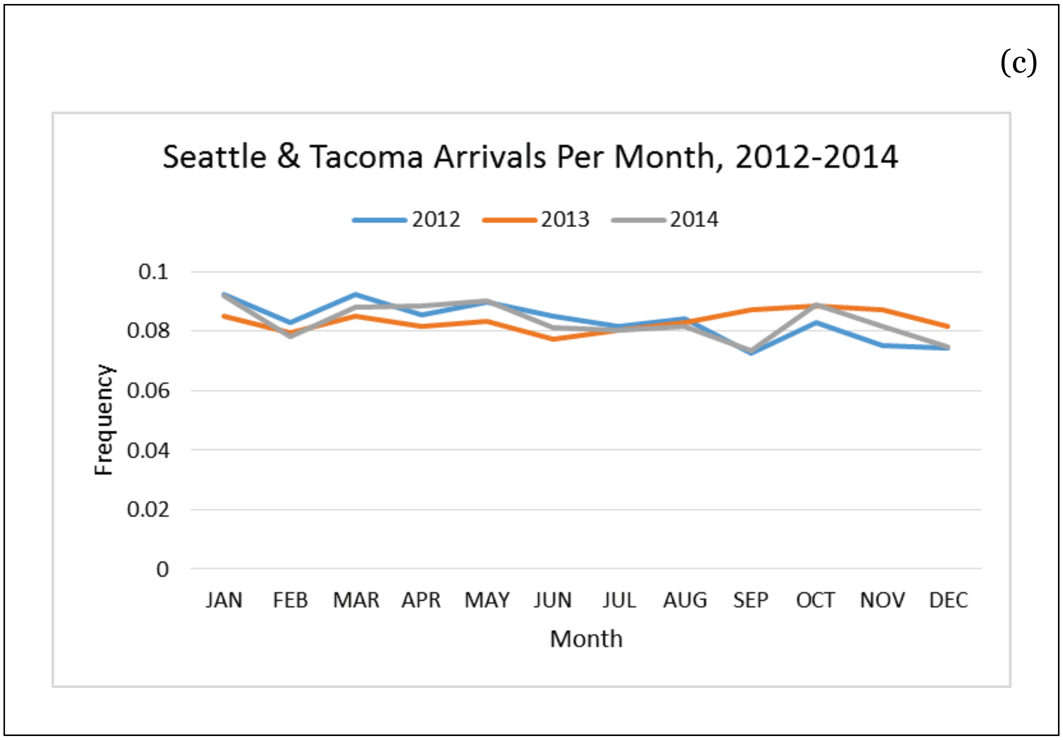
Figure 8.Monthly arrivals at (a) Tampa and (b) Columbia River showing seasonal increases in vessel arrivals. Columbia River had the widest range of monthly arrival frequencies. (c) Seattle and Tacoma had the narrowest range of arrival frequencies

(a)



(b)




(c)
Seattle & Tacoma Arrivals Per Month, 2012-2014
2012
2013
2014
Frequency
0.1
0.08
0.06
0.04
0.02
0
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
Month

5 Discussion

Prior to the availability of AIS data, a multiport analysis of this scope and detail was impractical. USACE typically analyzes vessel movement data provided from third parties such as shipping terminal operators or harbor pilots in the course of feasibility studies when considering harbor improvement. These sources may report vessel movement only as they apply to their operations. For example, a terminal operator may report the time a vessel arrives but would have limited information regarding the path taken by a vessel or the duration of its transit. Similarly, pilots may log only the time they embark a vessel. Data generally do not refer to the physical location of a vessel in transit but instead refer to the times of arrival or departure at a particular landmark. Each port has many potential sources, which must be consulted to obtain a complete picture of harbor operations. There is no standard format for compiling or reporting this information, which must be painstakingly gathered and organized for detailed analysis.

Recently, the Channel Portfolio Tool (CPT) (Mitchell 2012) has improved the ability to investigate the use of navigation channels in support of commodity movement. This tool relies on proprietary dock-level waterborne commerce data and uses spatial-join and shortest-path algorithms to aggregate and attribute cargo tonnage and dollar-value totals to the respective transited reaches. However, since the tool is based on annualized reported statistics, it does not incorporate the actual behavior of vessels while in transit. AIS data are available in real time and document the actual paths taken by vessels but lack the cargo details available from waterborne commerce data though CPT. Thus, the arrival process mining techniques discussed in this report serve to complement the CPT for providing USACE practitioners highly detailed project-specific vessel traffic information. Together, CPT- and AIS-derived information help to complete the waterfront operational picture.

AIS data provide a practical alternative to some traditional vessel observation methods as spatial and temporal information is captured in a single technology platform and avoids some problems encountered with traditional observation techniques (Scully and Mitchell 2015). Winkler et al. (2003), Briggs et al. (2004), and Maynord (2007) are examples of field collection efforts that would benefit from use of AIS data. For determining vessel arrival patterns and other behaviors, benefits over standard practice arise from the high granularity, standard format, automated collection,

lower acquisition cost, and centralized aggregation of AIS data. Operational benefits include continued collection in low visibility, darkness, and situations when vessels appear at differing locations with the channel, all of which were challenges described by Maynord (2007). Primarily, the decreased cost and increased scope of data availability that enable nationwide investigation of relevant topics are demonstrated here. AIS technology overcomes most environmental-related limitations arising from adverse weather conditions or poor visibility. However, AIS data collection is limited in some cases by line-of-sight obstruction from vessel broadcast and shore-side receiving stations, which must be considered when using AIS data for detailed analysis.

When arrivals are visualized as shown in Figure 6, periods of higher (or lower) use within a single port become obvious. Differences in usage patterns between ports also become obvious when these distributions are compared. Arrival frequency distributions may provide insight that enables port managers to make better informed decisions in support of operations.

The automated nature of AIS data broadcast and collection allows for automated repetition of desired analyses according to project-specific or programmatic goals. Data for an entire port can be obtained from a single source by employing methods described in this report. Consider that this type of tidal analysis could be performed year over year to monitor changes in vessel behavior. Alternatively, tidal analysis could be performed after harbor improvements to validate assumptions made regarding the use of available water levels, which would inform future design efforts.

By investigating the distribution of vessel transits with regard to tidal elevation, it becomes possible to attempt grouping and categorizing ports based on the usage patterns of incident vessels. For instance, Figure 9 depicts the proportion of vessels calling above each port's respective high-tide threshold versus the percentage of vessels calling below that port's low-tide threshold. While the average of the fraction of low-tide traffic is similar across regions, Atlantic ports have a range of T_{25} values triple that of Gulf ports and nearly double that of Pacific ports. Similar observations may be made with regard to the range of T_{75} values. Given that vessels arriving anywhere are in theory free to call at any tidal stage, the cause and meaning of these observations require further study to be determined.

Figure 9. Visualization of fraction of vessels arriving above vs. below respective tidal elevation thresholds by region. Much more variation is evident at Atlantic and Pacific ports than at Gulf ports.

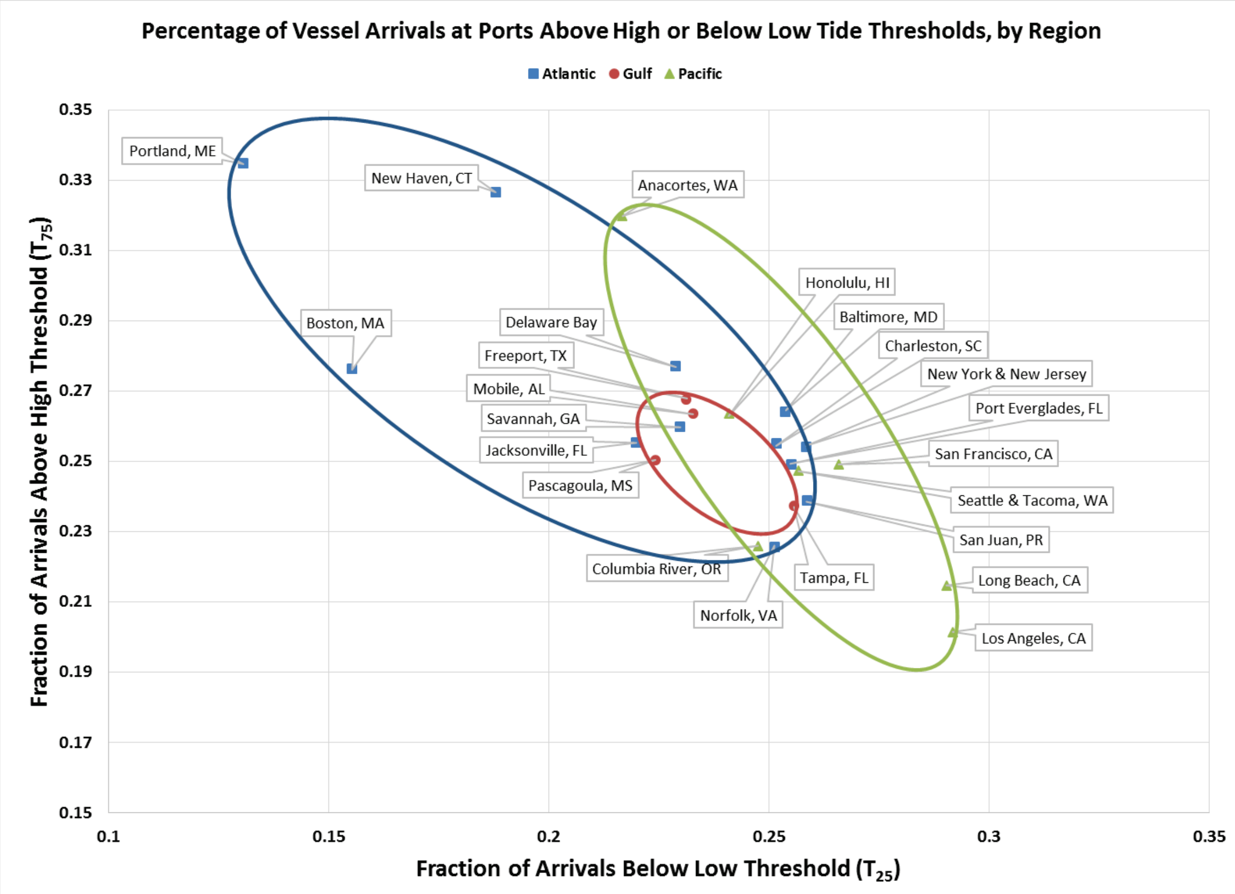


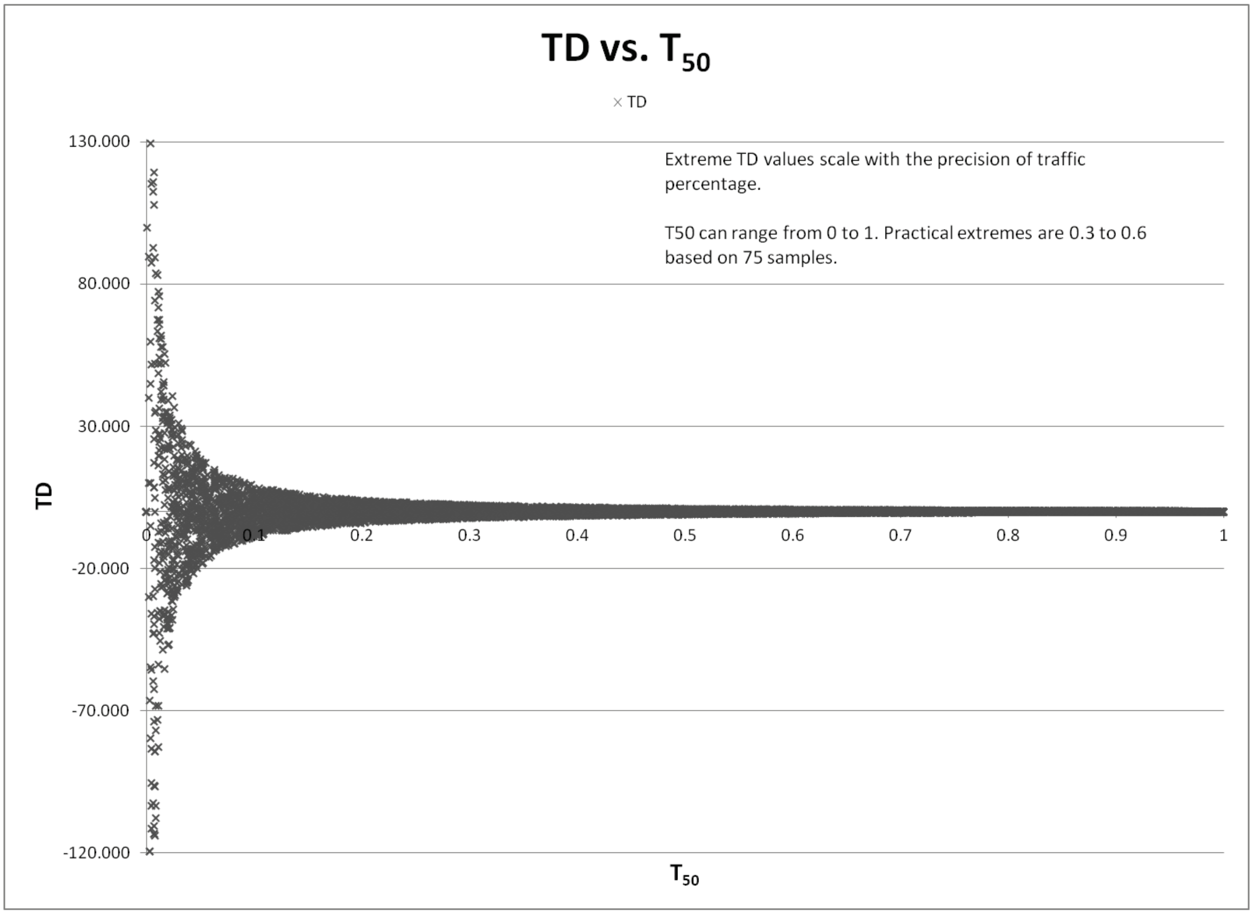
Figure 10 highlights the possibility of using the tidal dependence metric to monitor changes in vessel distribution across the tidal cycle. Emergent trends may be used to inform decisions related to maintenance or expansion investment priorities. For instance, Savannah, GA, shows an increasing trend in TD values over this 3-year sample. This is too brief a record from which to draw strong conclusions, but Savannah is presently undergoing harbor deepening; the port is well documented as being visited more frequently by vessels that are tidally constrained due to large drafts relative to available depth. The decreasing trends in TD value at Portland and Los Angeles, on either end of the spectrum, are also interesting. Further conclusions of the relevance or stability of these trends can only be made by expanding the temporal scope of investigation.

Figure 10. TD values by port and year visualized for year-over-year stability.

	TD Value by Port and Year		
	2012	2013	2014
Los Angeles, CA	-0.16	-0.18	-0.19
Long Beach, CA	-0.11	-0.20	-0.20
Norfolk, VA	-0.05	-0.08	-0.02
San Juan, PR	-0.02	-0.05	-0.05
Tampa, FL	-0.05	-0.04	-0.02
San Francisco,CA	-0.02	-0.05	-0.04
Seattle & Tacoma, WA	0.00	-0.03	-0.03
Port Everglades, FL	0.01	-0.03	-0.02
New York & New Jersey	-0.04	0.00	0.01
Columbia River, OR	-0.04	0.02	0.00
Charleston, SC	0.05	-0.03	0.01
Baltimore, MD	-0.04	0.04	0.05
Honolulu, HI	0.09	0.04	0.01
Pascagoula, MS	0.04	0.09	0.02
Savannah, GA	0.00	0.07	0.11
Mobile, AL	0.08	0.02	0.09
Delaware Bay, DE	0.03	0.16	0.10
Jacksonville, FL	0.10	0.10	0.01
Freeport, TX	0.10	0.06	0.07
Boston, MA	0.23	0.16	0.25
Anacortes, WA	0.52	0.08	0.11
New Haven, CT	0.41	0.19	0.26
Portland, ME	0.55	0.42	0.21

Figure 11 shows the solution space of the TD metric for all values of T_{25}, T_{50}, and T_{75}. This figure makes it clear that the metric is highly sensitive to reductions in mid-tide traffic, especially when the T50 fraction approaches 10% of the total traffic population. Below 10% of vessels operating at mid tide, the TD metric is increasingly sensitive to imbalances between the high- and low-tide traffic fractions. Within the full range of possible T_{50} values, the raw T_{25} and T_{75} values inform cases where high and low tide are approximately equal.

Figure 11. Numerical solution for possible of TD. All ports investigated for this work fall within the range of $0.3 \leq T_{50} \leq 0.6$.



Among the observed ports, the mid-tide portion of traffic ranged from 0.46 at Anacortes, WA, to 0.57 at Boston, MA. Within this range of mid-tide percentage, the maximum expected magnitude of TD values range from +/- 1.17 to +/- 0.75. The minimum and maximum calculated values, -0.20 at Long Beach, CA (2013 and 2014), and 0.55, at Portland, ME (2012), respectively, fall within this range. The TD metric as currently formulated is limited by the fact that the variability of resultant values is perhaps too narrow to make meaningful comparisons across ports with T50 values near 0.5, especially when T25 and T50 values are approximately equal.

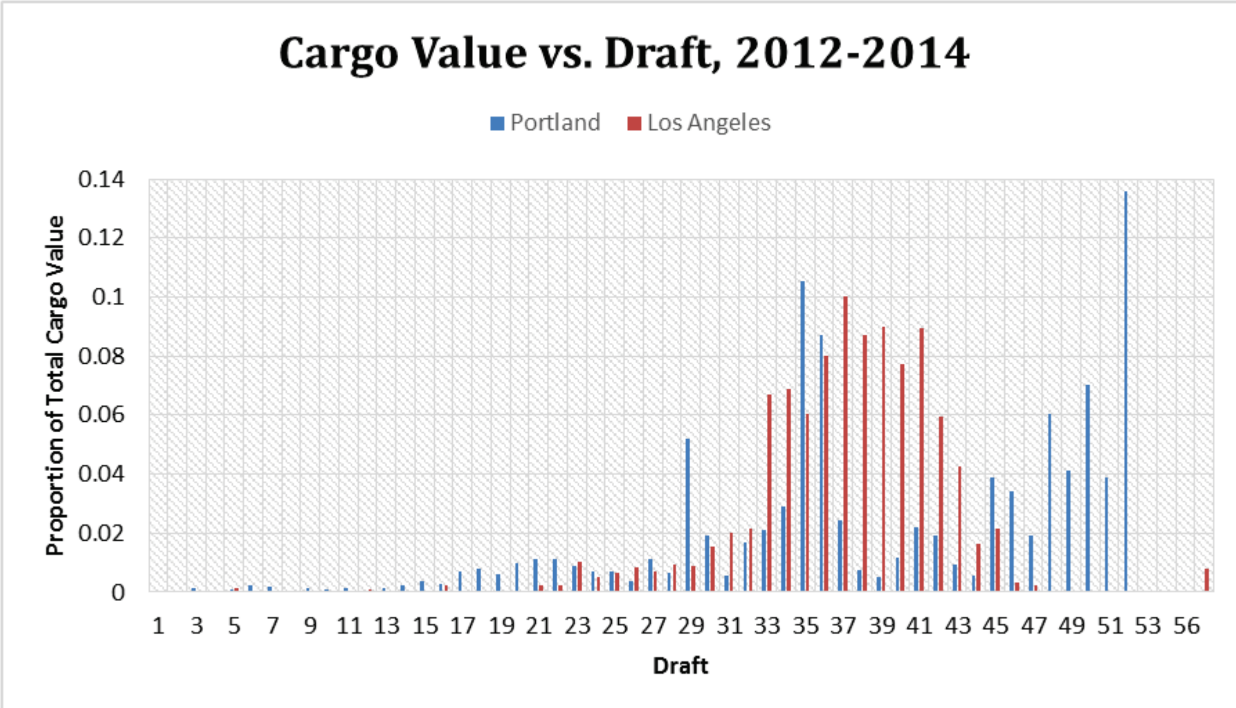
Note the vessel arrival behavior with regard to the value of the TD metric. The maximum individual and average values (0.55 and 0.39, respectively) were observed at Portland, ME. Portland has nearly triple the volume of arrivals above the 75th percentile water elevation (33%) compared to arrivals below the 25th (13%) on average. Conversely, Los Angeles, CA,

demonstrated the lowest average TD value of -0.18 and had only 45% more low-tide calls (29%) compared to arrivals at high tide (20%). Long Beach, CA, had the lowest individual TD value of -0.20 with traffic composition similar to Los Angeles. Mid-tide calls were nearly evenly distributed at Portland and Los Angeles, with 53% and 51%, respectively, while Long Beach had 50% traffic during mid-tides.

The arrival frequency at Los Angeles and Portland, shown in Figure 6, indicates that temporal clustering is much stronger at Los Angeles than at Portland. As average tidal frequency and the 24 hr day are unequal, it is expected that vessels taking advantage of high tide would show weak clustering behavior due to the shifting time of tidal events compared to regular daily schedules. Instead, vessel arrival patterns would mimic the occurrence pattern of high-tide events. At Los Angeles, where call clustering is strongly apparent and indicative of regular daily operations, low- and high-tide arrivals are much more balanced. This is to be expected, again because tidal frequency is out of sync with a 24 hr daily schedule. The interarrival time distribution, shown in Figure 4, indicates that vessel calls are spread out at Portland and are very rapid at Los Angeles (which had approximately nine times as much traffic). This further suggests a relationship between traffic volume, temporal clustering, and the TD value. Still, the preference for low tide at Los Angeles is curious given the strong clustering pattern.

It is likely that the variation in vessel arrival behavior is related to the vessel types and the drafts at which those vessels arrive. Figure 12 displays the fractional value of cargo moved through Portland, ME, and Los Angeles, CA, from 2012 through 2014 with respect to draft, as reported in Waterborne Commerce Statistics Data accessed via CPT. The volume of throughput is substantially larger at Los Angeles (60 million tons, annually) than at Portland, (11 million tons, annually). Los Angeles has an authorized entrance channel depth of 53 ft below MLLW but logged vessel arrivals with maximum drafts of 57 ft. Portland, with an authorized entrance channel depth of 45 ft below MLLW, logged vessel arrivals with maximum drafts of 52 ft during the study period.

Figure 12.Vessel traffic at Portland, ME, has a significant value of cargo moving with vessels at its deepest drafts. At Los Angeles, CA, the value of cargo transported at the deepest drafts reported in the harbor is marginal.



In both cases, commodity data include vessels with drafts greater than the respective authorized channel depths, indicating reliance on additional channel depth, very likely resulting from tidal water level fluctuations. The average range of tidal predictions for 2012–2014 was 8.88 ft in Los Angeles and 13.84 ft in Portland. In Los Angeles, additional depth from tide accounts for 16.8% of the authorized channel depth. In Portland, tidal depth provides an additional 30.8% beyond authorized depth.

The draft of shipments in excess of project depth, 4 ft at Los Angeles and 7 ft at Portland, represents 7.5% and 15.6% of authorized depth, respectively. The draft in excess of project depth represented 45% of the observed range of tidal predictions at Los Angeles and 51% at Portland.

Portland's cargo is predominantly bulk products (99% by tonnage, Figure 13) and is heavily weighted toward its deepest drafting vessels. Approximately 40% of cargo value moves at drafts larger than the authorized project depth, indicating that in all likelihood it transited when water levels were above MLLW. However, less than 1% of cargo value at Los Angeles, which is predominantly containerized products (77% by tonnage, Figure 14), moves on vessels with drafts larger than the authorized project depth. Based on AIS data, on average, 33% of traffic

moved above the 75th percentile predicted tidal elevation at Portland. At Los Angeles, only 20% of traffic moved above the 75th percentile predicted tidal elevation. While each port is using approximately half of the available tidal depth, Portland's increased channel depth as a fraction of authorized channel depth is approximately twice that of Los Angeles. The benefit of using that additional depth is much higher, in tonnage and value terms at Portland than at Los Angeles.

The preference for any tide stage may have multiple interpretations. For example, the preference for higher tide elevations at Portland may reflect opportunism on the part of vessel operations incented to land the maximum draft possible there. Given that more than 50% of traffic in Portland moves during mid-tide elevations, this interpretation seems more likely than the alternative interpretation that bulk cargo vessel operators might prefer to avoid tidal currents associated with mid-tide elevations. In Los Angeles temporal clustering, low traffic density during high tide and limited value of cargo moved at drafts in excess of authorized project depth may mean that vessel schedule and crane productivity dominates vessel arrival behavior with available water depth being generally less important. However, detailed analysis of the motivating factors underlying these general observations are beyond the scope of this investigation.

Figure 13.Portland, ME, cargo is predominantly bulk commodities. On average, nearly 14% of cargo moved at 52 ft of draft, the deepest recorded during this period.

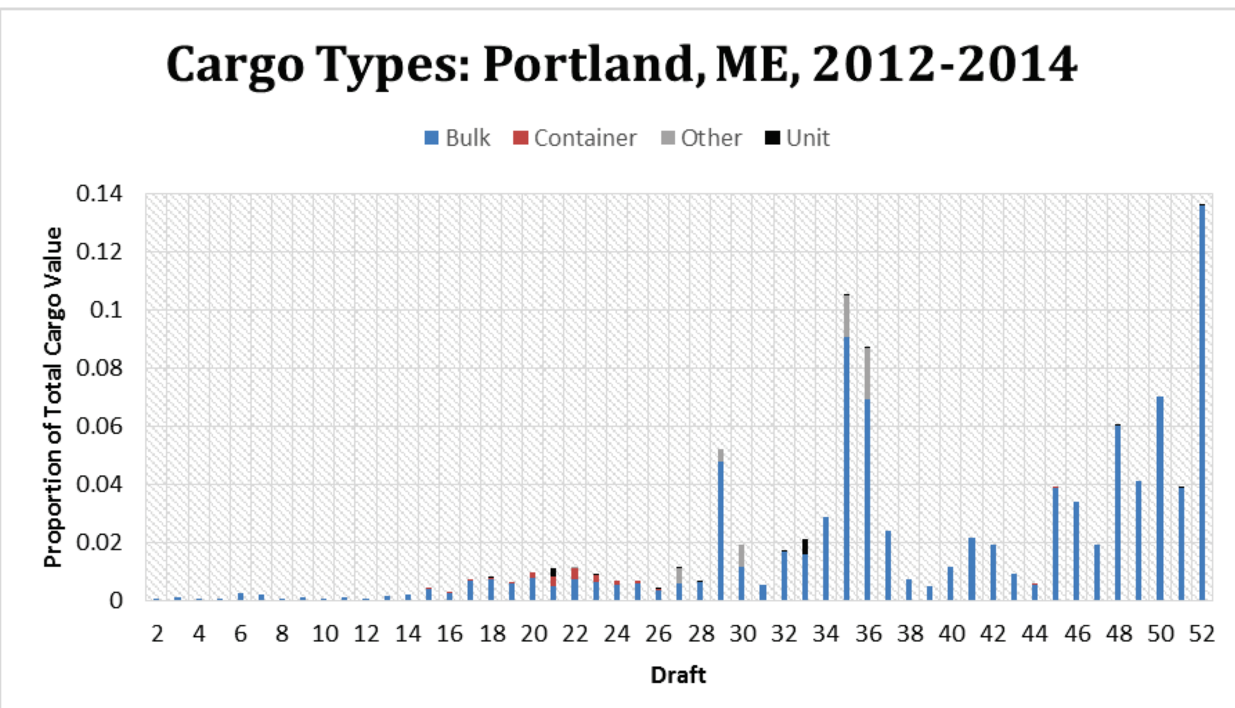
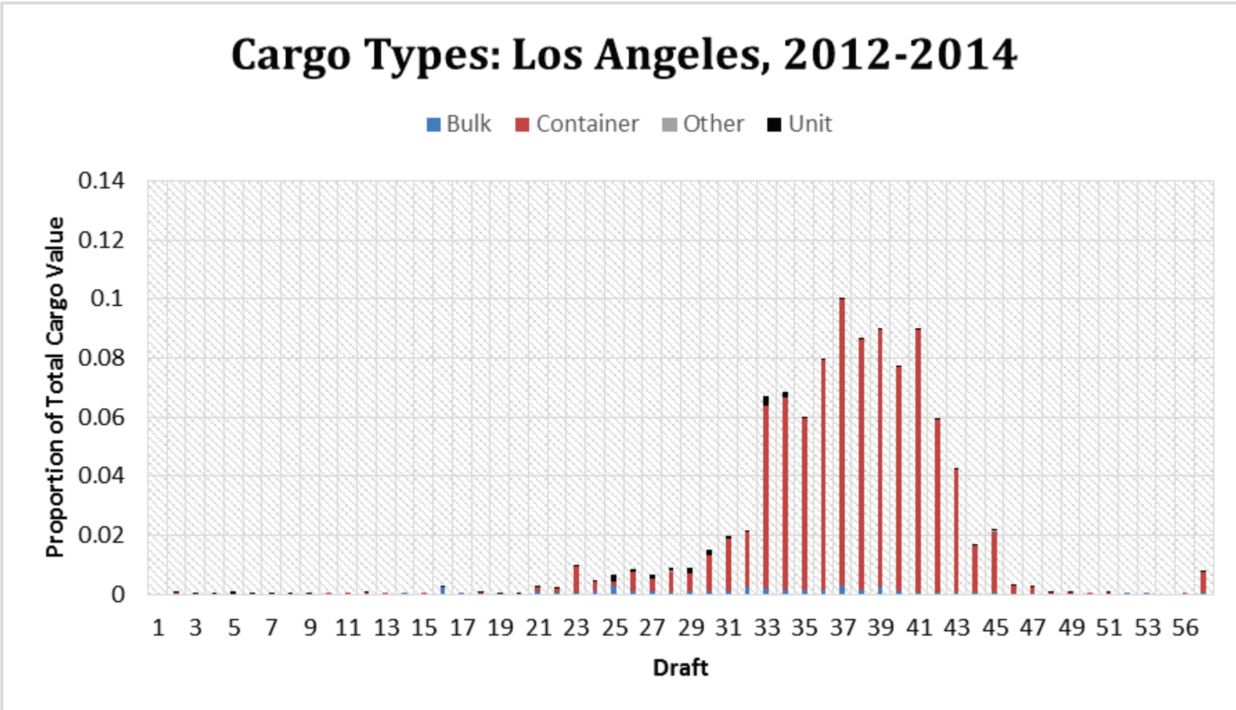


Figure 14. Los Angeles, CA, cargo is predominantly containerized. Approximately 1% of cargo on average moved at the deepest recorded draft of 57 ft during this period.



6 Conclusion

This investigation has identified AIS data as an information source valuable for collection of vessel-related movement information. Provided that vessels of interest can be validated through authoritative means, AIS provides a far-reaching remote-sensing platform that will enable practitioners to efficiently analyze vessels in transit. The high dimensionality of AIS data provides numerous methods for filtering data, making it possible to analyze vessel movements precisely at an unprecedented breadth of scope.

This investigation further demonstrated the TD metric methodology as a simple and intuitive measure of vessel performance within USACE-maintained navigation entrance channels when vessel TD imbalances are present. It provided a relative ranking of ports within the USACE navigation portfolio based on when vessels arrive with respect to predicted tidal elevation. When extreme (high or low) tidal preference is present but balanced, the traffic fractions T_{25}, T_{50}, T_{75}, are more informative.

The fusion of AIS data with tidal predictions demonstrates one of many potential analyses coupling vessel and environmental forcing data. AIS is an important data source to consider when investigating other navigation-related topics, especially when the behavior of vessels in transit is relevant to the problem under consideration.

Finally, the spatio-temporal nature and high granularity of AIS data make further integration of vessel transit information with commerce and channel condition data a worthwhile area for future research and development. In the case of Portland, ME, the highest observed TD value was associated with a substantial value of port cargo being moved at vessel drafts in excess of authorized channel depths. In Los Angeles, the lowest observed TD value was associated with temporally clustered vessel arrivals. While both observations are interesting in their own right, it was demonstrated that AIS analysis methods serve to complement existing tools, such as CPT, in providing USACE practitioners with richly detailed information that helps to complete the picture of navigation operations and that may assist waterway managers in making complex channel design and maintenance decisions.

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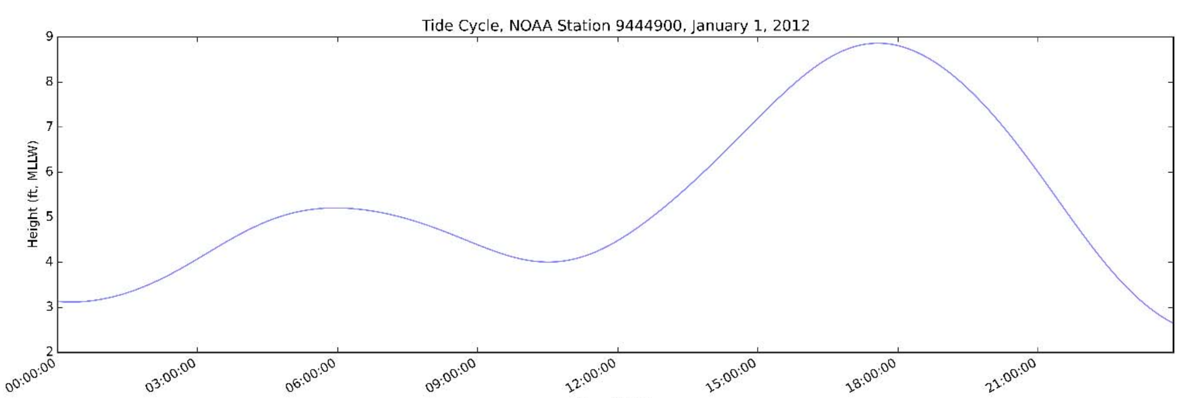
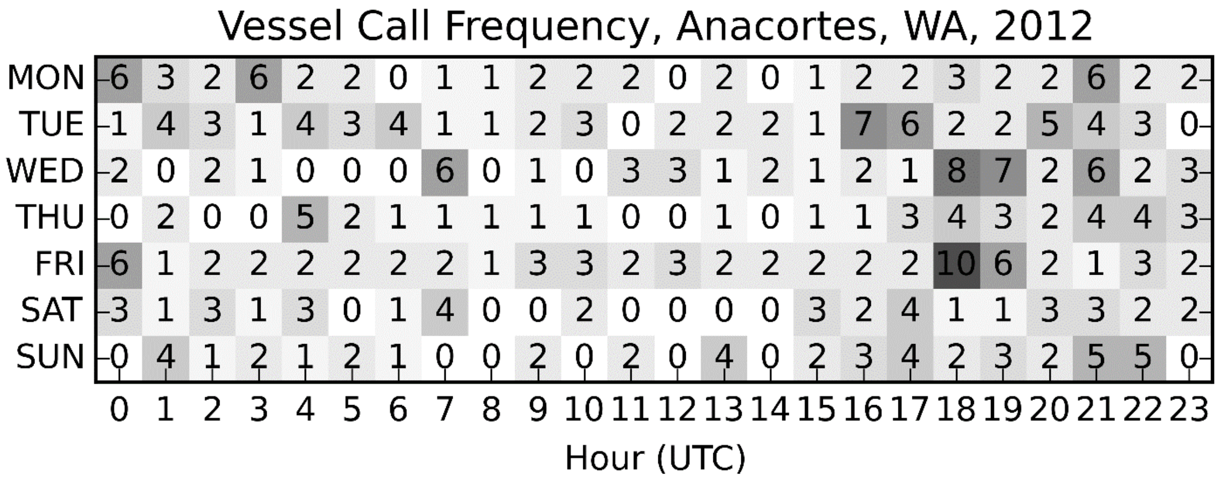
Appendix A: Port Reference Lines

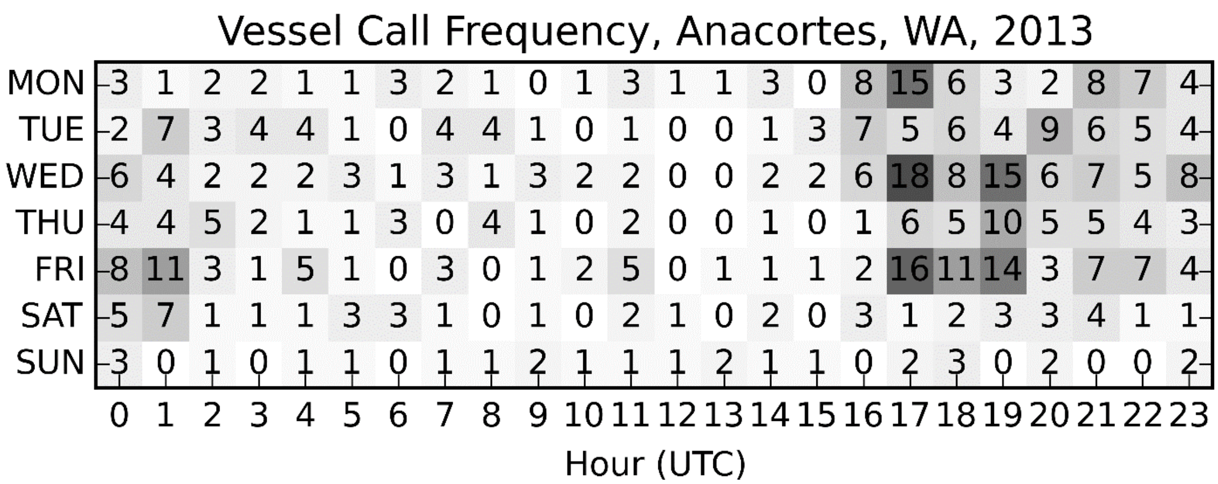
Port of Interest: **Anacortes, WA**

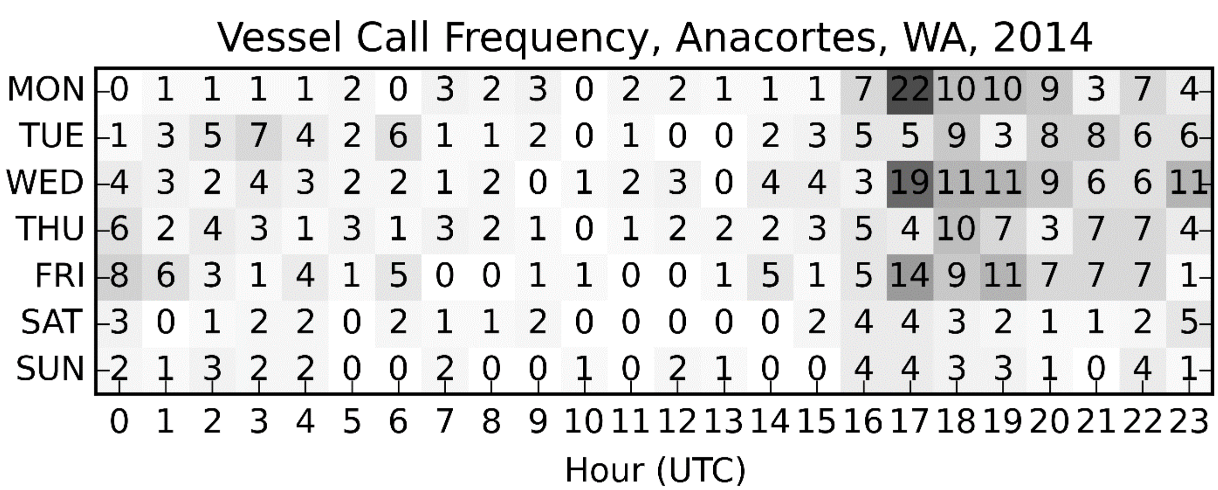
Tide Station Number: 9444900

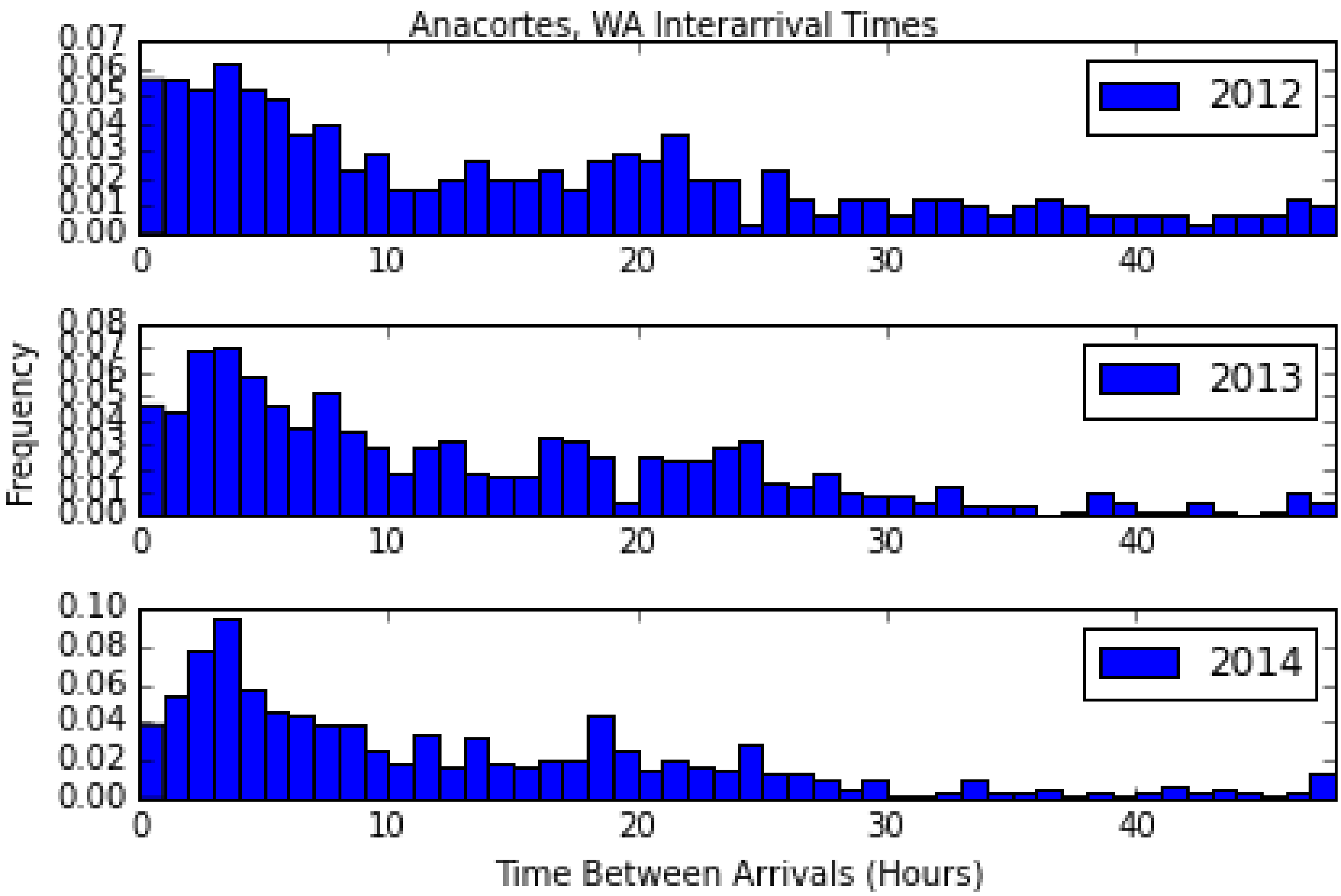
Year	Tide Range (Ft.)	Z_{25} (Ft.)	Z_{75} (Ft.)	T_{25}	T_{50}	T_{75}	TD	Arrivals
2012	13.13	3.13	7.11	0.19	0.41	0.40	0.52	358
2013	13.01	3.20	7.04	0.24	0.48	0.28	0.08	513
2014	12.79	3.23	7.01	0.22	0.50	0.28	0.11	549



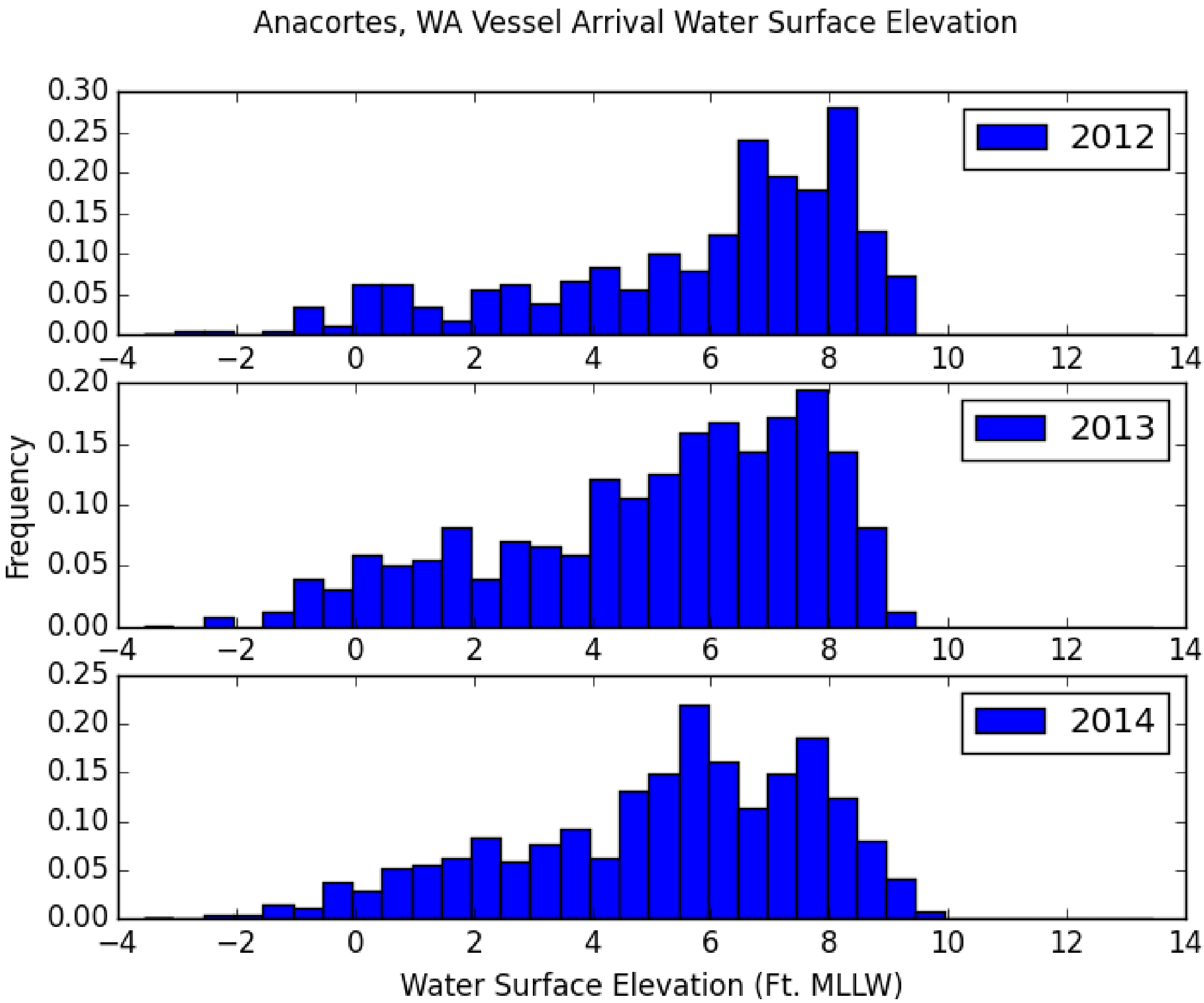

Vessel Call Frequency, Anacortes, WA, 2012
MON
TUE
WED
THU
FRI
SAT
SUN
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)

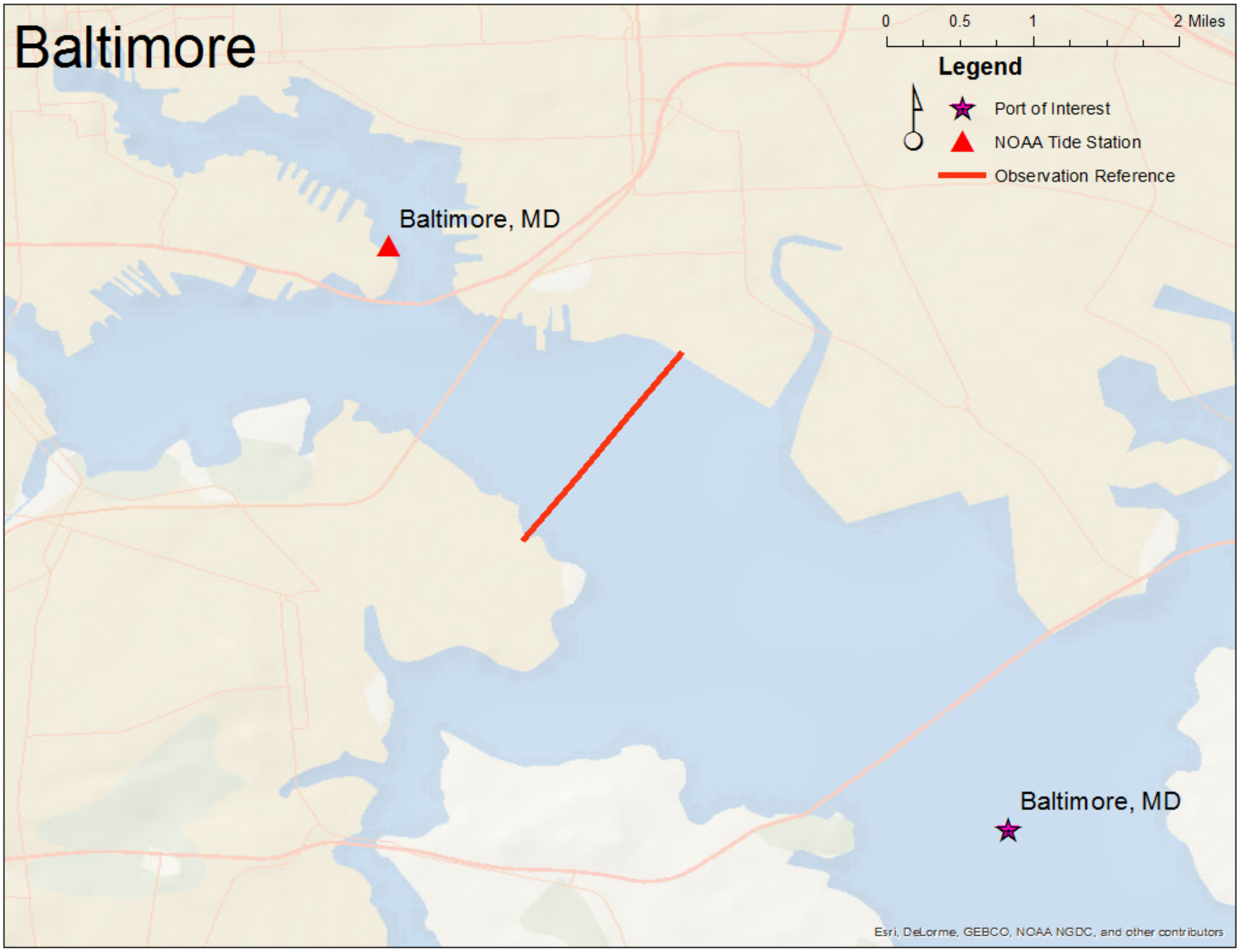

Vessel Call Frequency, Anacortes, WA, 2013
MON
TUE
WED
THU
FRI
SAT
SUN
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)


Vessel Call Frequency, Anacortes, WA, 2014
MON
TUE
WED
THU
FRI
SAT
SUN
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)



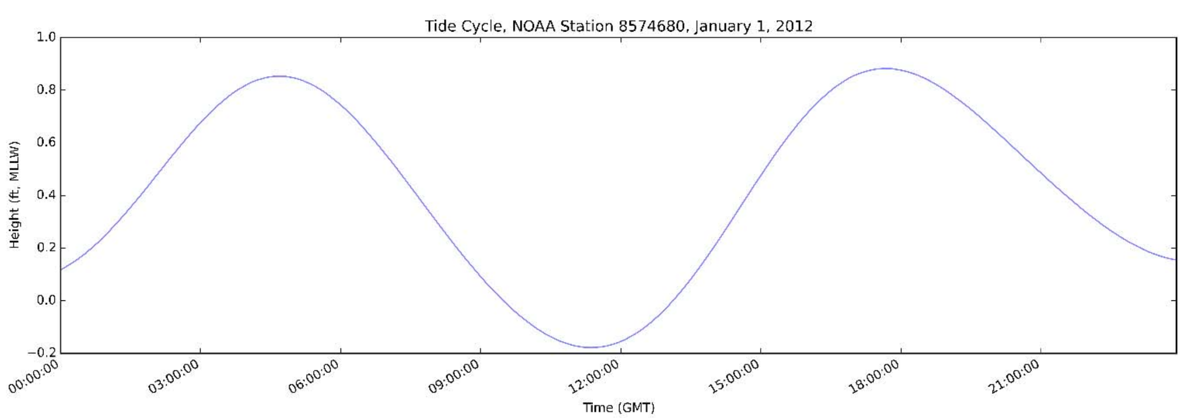
Anacortes, WA Interarrival Times
2012
2013
2014
Frequency
Time Between Arrivals (Hours)
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0.08
0.10
0
10
20
30
40

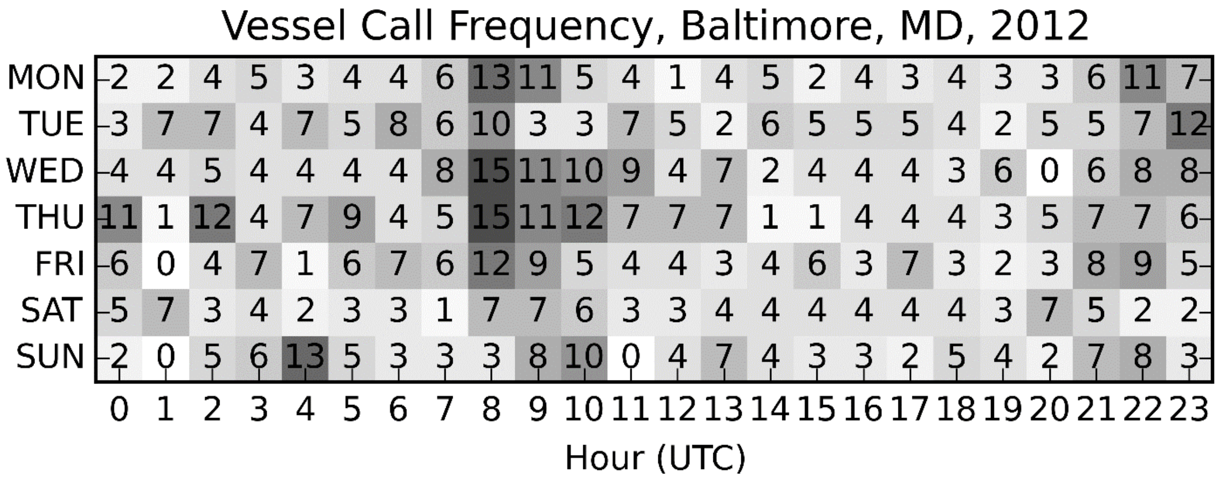

Anacortes, WA Vessel Arrival Water Surface Elevation
2012
2013
2014
Frequency
Water Surface Elevation (Ft. MLLW)
0.30
0.25
0.20
0.15
0.10
0.05
0.00
−4
−2
0
2
4
6
8
10
12
14

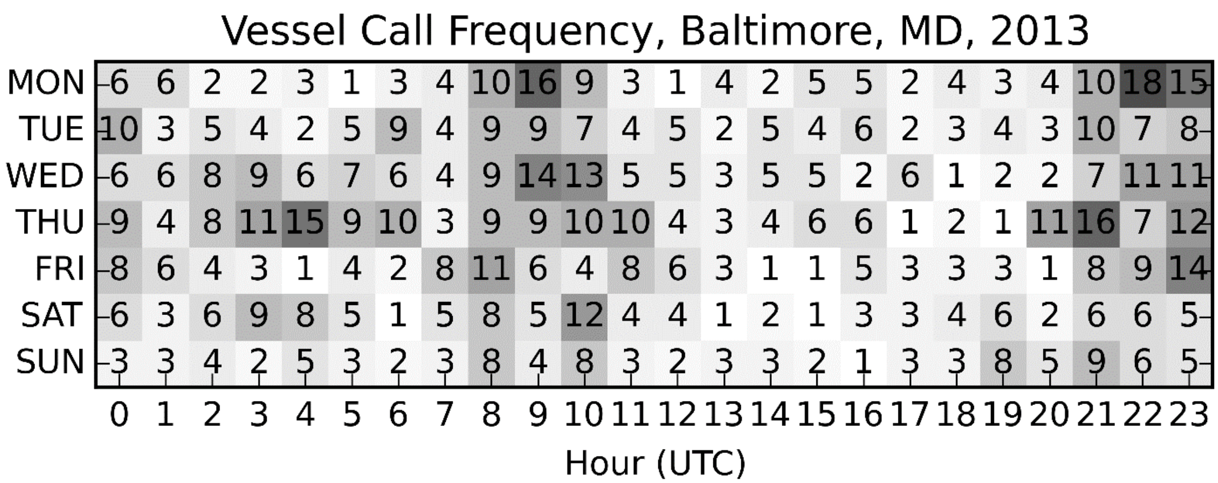


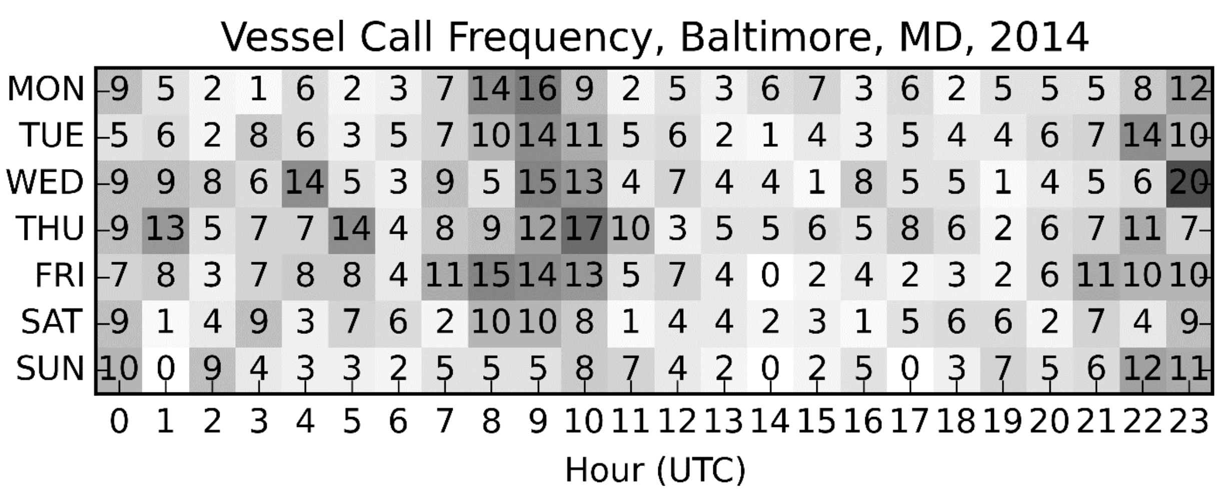
Port of Interest: **Baltimore, MD**
Tide Station Number: 8574680

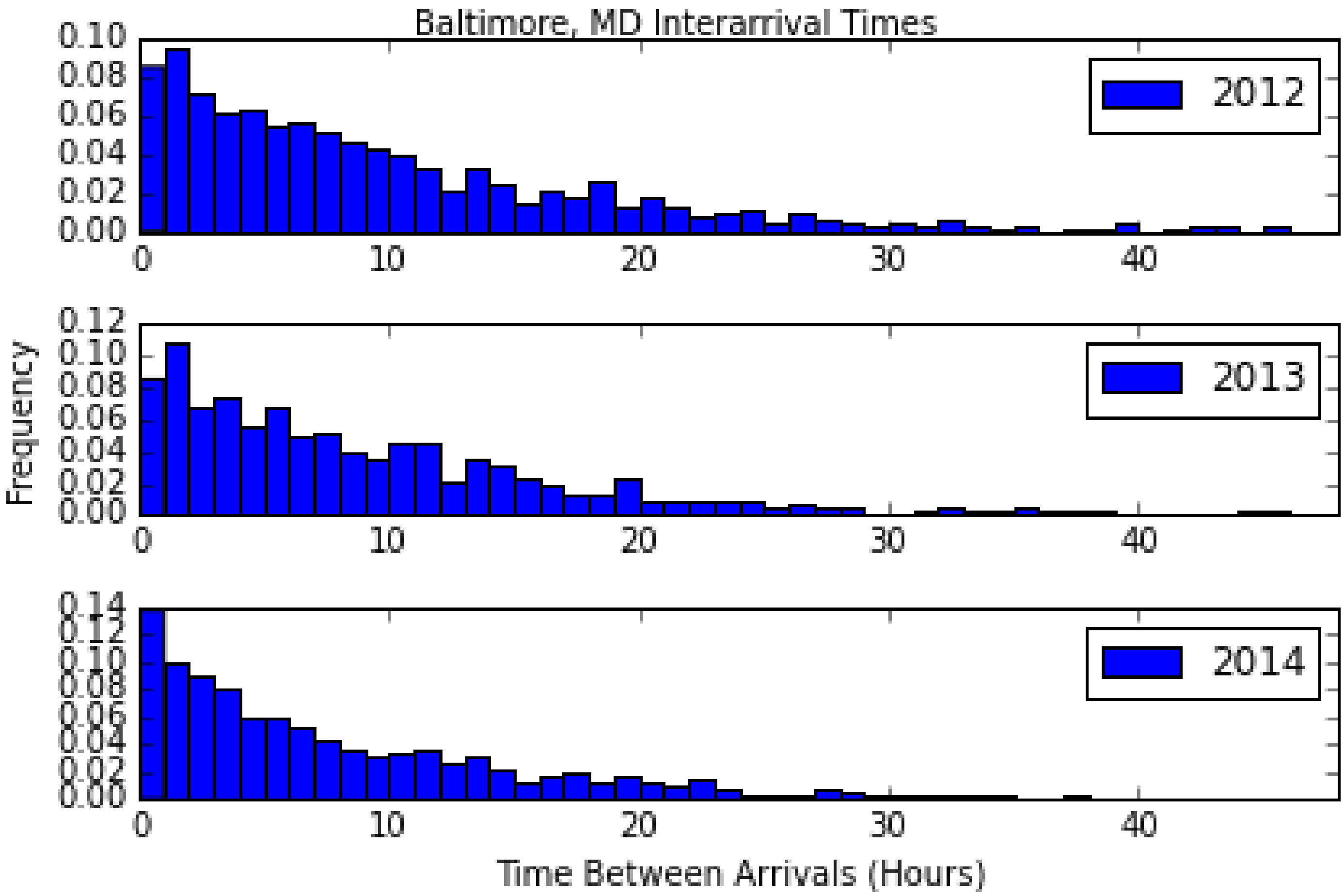
Year	Tide Range (Ft.)	Z_{25} (Ft.)	Z_{75} (Ft.)	T_{25}	T_{50}	T_{75}	TD	Arrivals
2012	2.72	0.43	1.16	0.28	0.46	0.26	-0.04	872
2013	2.75	0.43	1.17	0.24	0.50	0.26	0.04	936
2014	2.67	0.43	1.17	0.24	0.49	0.27	0.05	1052

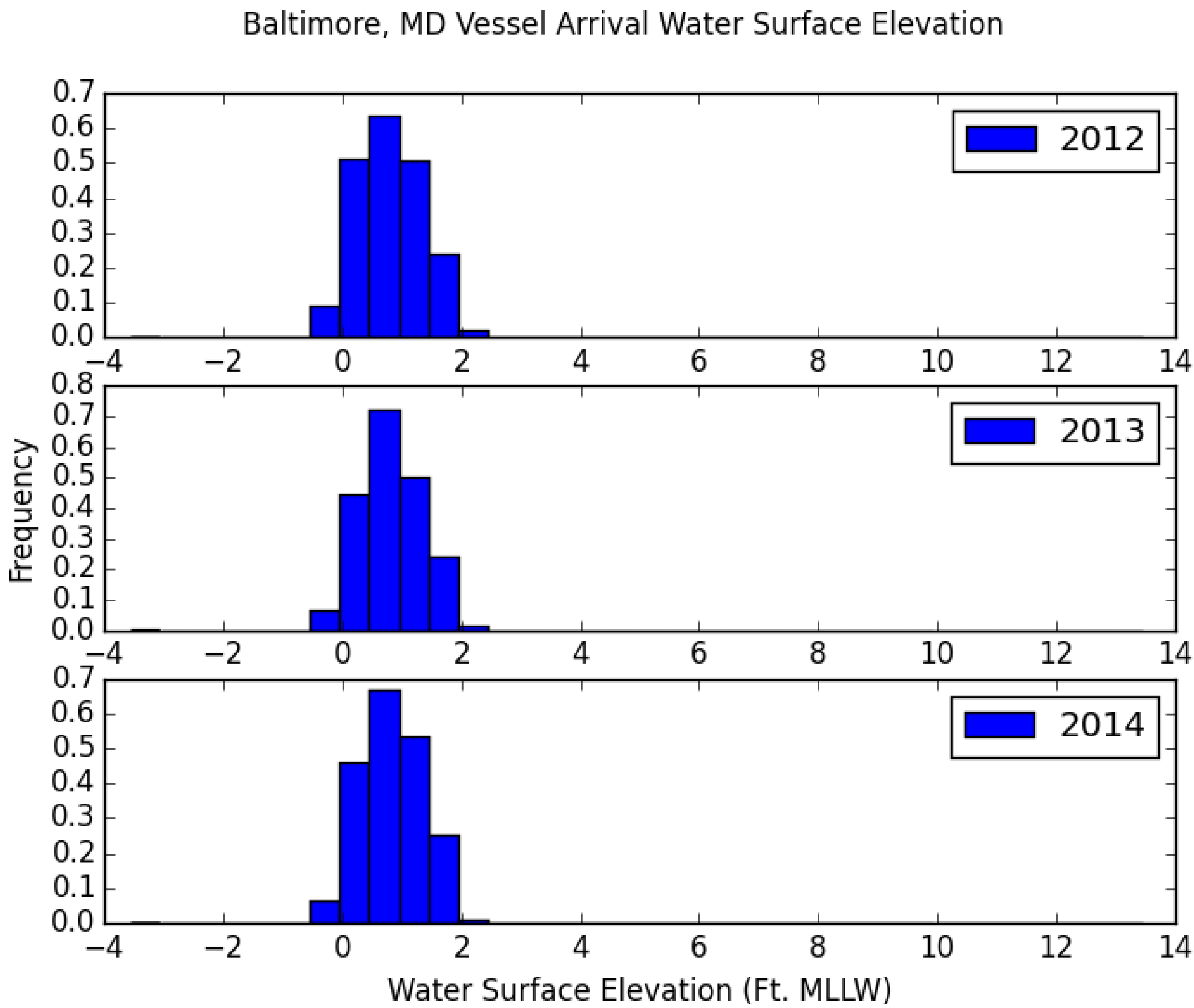


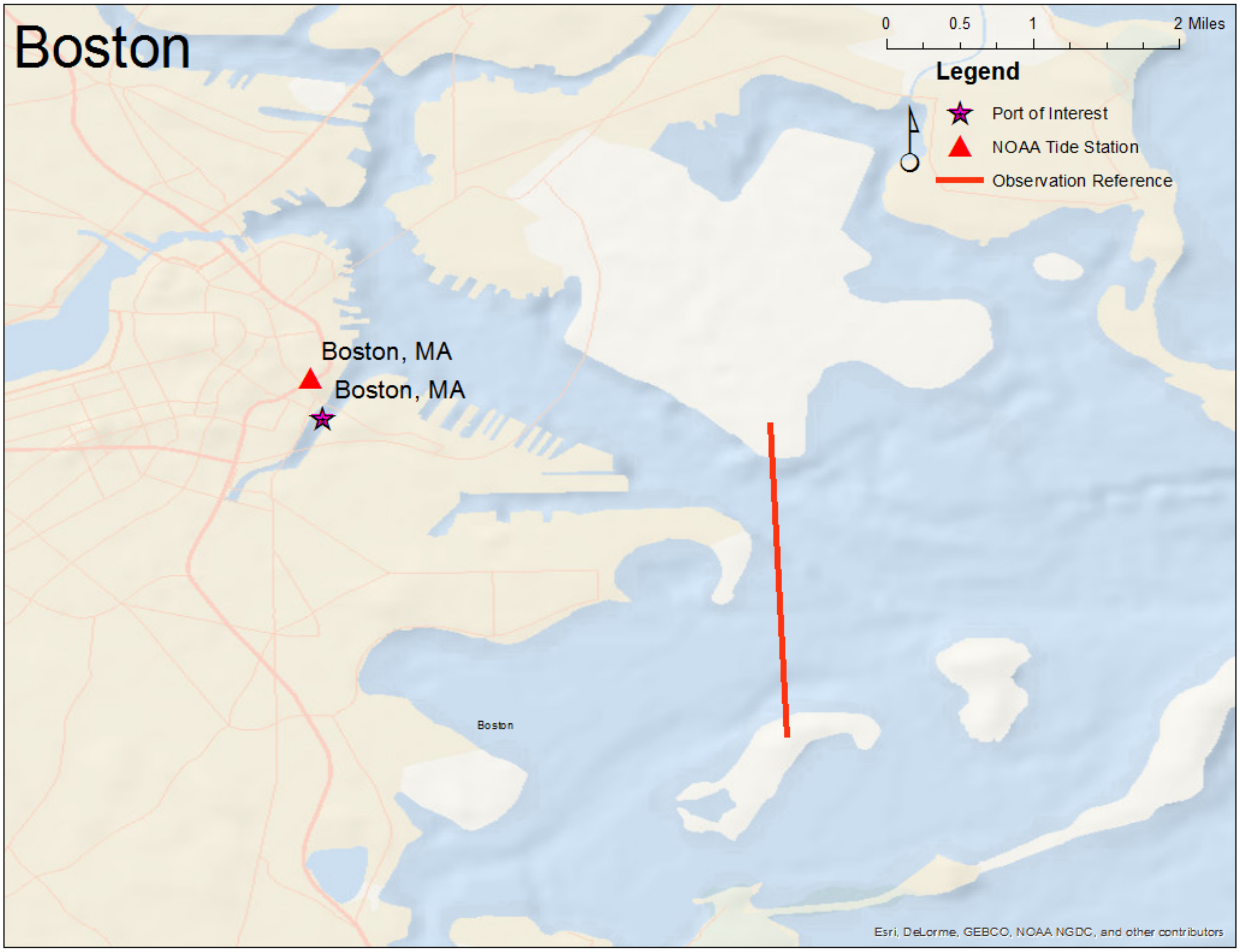

Vessel Call Frequency, Baltimore, MD, 2012
MON 2 2 4 5 3 4 4 6 13 11 5 4 1 4 5 2 4 3 4 3 3 6 11 7
TUE 3 7 7 4 7 5 8 6 10 3 3 7 5 2 6 5 5 5 4 2 5 5 7 12
WED 4 4 5 4 4 4 4 8 15 11 10 9 4 7 2 4 4 4 3 6 0 6 8 8
THU 11 1 12 4 7 9 4 5 15 11 12 7 7 7 1 1 4 4 4 3 5 7 7 6
FRI 6 0 4 7 1 6 7 6 12 9 5 4 4 3 4 6 3 7 3 2 3 8 9 5
SAT 5 7 3 4 2 3 3 1 7 7 6 3 3 4 4 4 4 4 4 3 7 5 2 2
SUN 2 0 5 6 13 5 3 3 3 8 10 0 4 7 4 3 3 2 5 4 2 7 8 3
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)


Vessel Call Frequency, Baltimore, MD, 2013
MON 6 6 2 2 3 1 3 4 10 16 9 3 1 4 2 5 5 2 4 3 4 10 18 15
TUE 10 3 5 4 2 5 9 4 9 9 7 4 5 2 5 4 6 2 3 4 3 10 7 8
WED 6 6 8 9 6 7 6 4 9 14 13 5 5 3 5 5 2 6 1 2 2 7 11 11
THU 9 4 8 11 15 9 10 3 9 9 10 10 4 3 4 6 6 1 2 1 11 16 7 12
FRI 8 6 4 3 1 4 2 8 11 6 4 8 6 3 1 1 5 3 3 3 1 8 9 14
SAT 6 3 6 9 8 5 1 5 8 5 12 4 4 1 2 1 3 3 4 6 2 6 6 5
SUN 3 3 4 2 5 3 2 3 8 4 8 3 2 3 3 2 1 3 3 8 5 9 6 5
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)


Vessel Call Frequency, Baltimore, MD, 2014
MON 9 5 2 1 6 2 3 7 14 16 9 2 5 3 6 7 3 6 2 5 5 5 8 12
TUE 5 6 2 8 6 3 5 7 10 14 11 5 6 2 1 4 3 5 4 4 6 7 14 10
WED 9 9 8 6 14 5 3 9 5 15 13 4 7 4 4 1 8 5 5 1 4 5 6 20
THU 9 13 5 7 7 14 4 8 9 12 17 10 3 5 5 6 5 8 6 2 6 7 11 7
FRI 7 8 3 7 8 8 4 11 15 14 13 5 7 4 0 2 4 2 3 2 6 11 10 10
SAT 9 1 4 9 3 7 6 2 10 10 8 1 4 4 2 3 1 5 6 6 2 7 4 9
SUN 10 0 9 4 3 3 2 5 5 5 8 7 4 2 0 2 5 0 3 7 5 6 12 11
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)

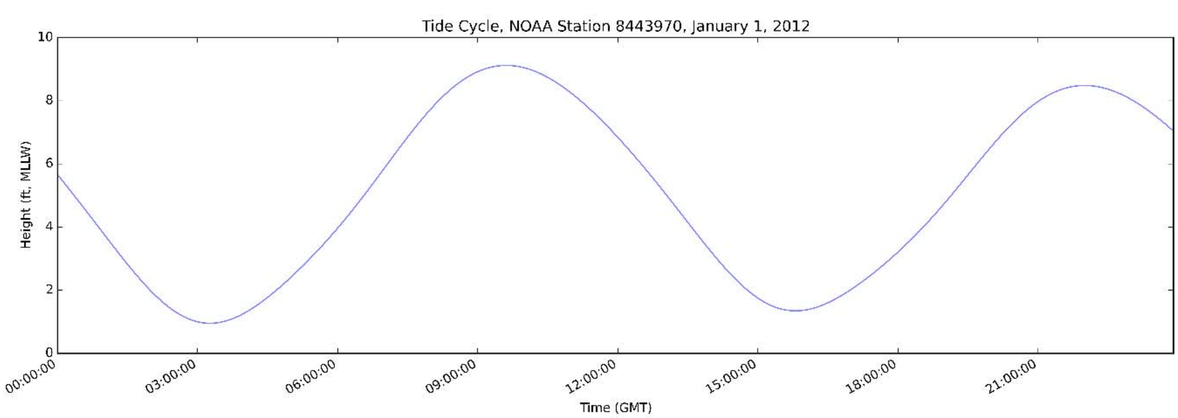

Baltimore, MD Interarrival Times
2012
2013
2014
Frequency
Time Between Arrivals (Hours)
0.10
0.08
0.06
0.04
0.02
0.00
0.12
0.14
0
10
20
30
40

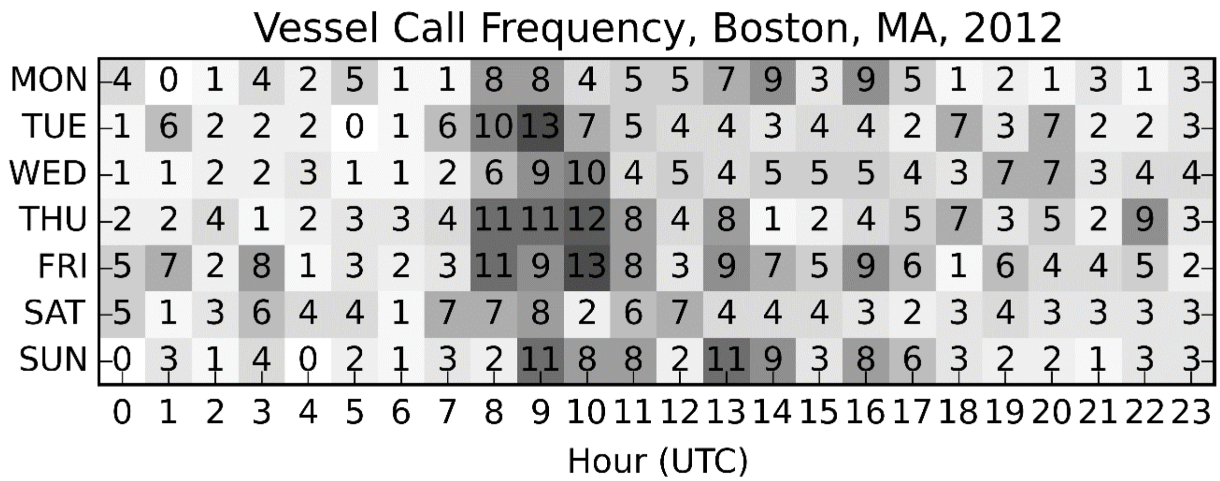

Baltimore, MD Vessel Arrival Water Surface Elevation
2012
2013
2014
Frequency
Water Surface Elevation (Ft. MLLW)

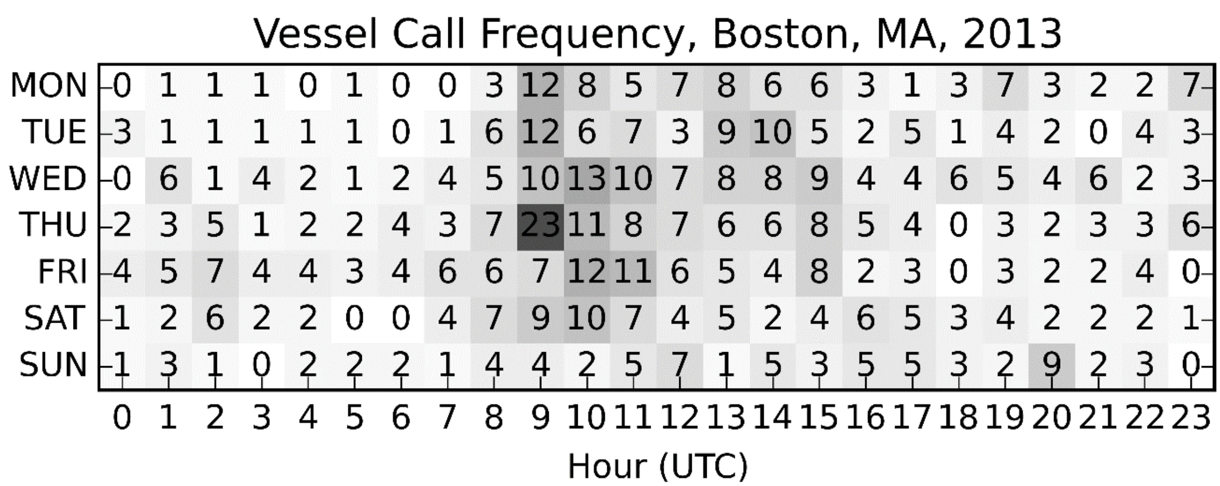


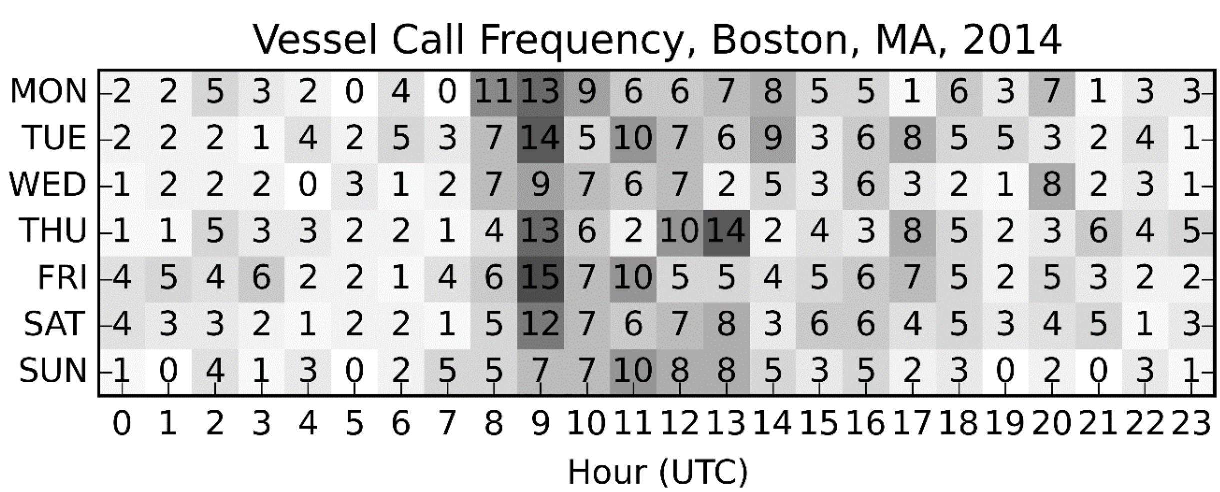
Port of Interest: **Boston, MA**
Tide Station Number: 8443970

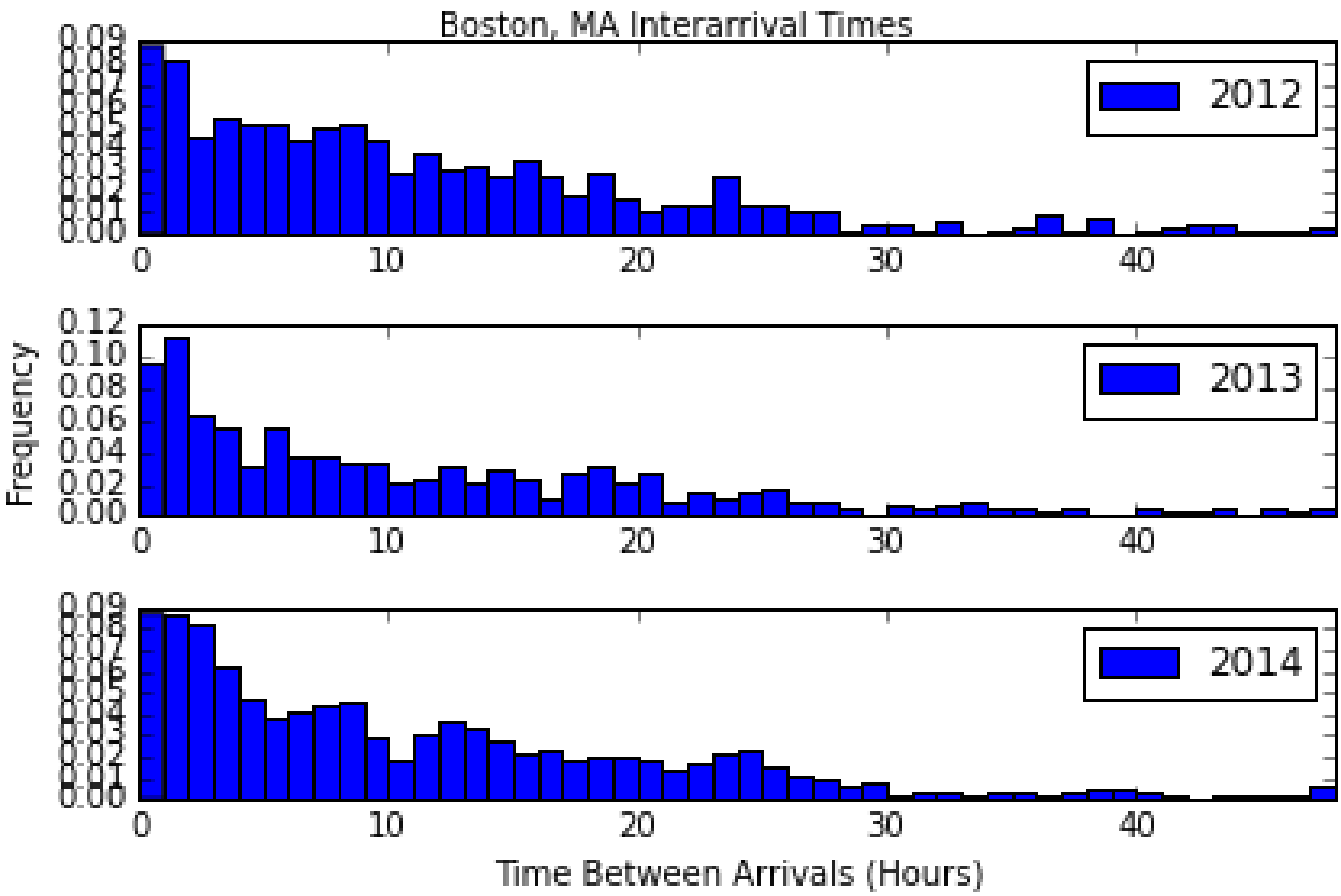
Year	Tide Range (Ft.)	Z_{25} (Ft.)	Z_{75} (Ft.)	T_{25}	T_{50}	T_{75}	TD	Arrivals
2012	14.49	2.03	8.36	0.14	0.59	0.27	0.23	732
2013	14.31	1.99	8.41	0.18	0.55	0.27	0.16	697
2014	14.49	1.95	8.46	0.15	0.56	0.29	0.25	727

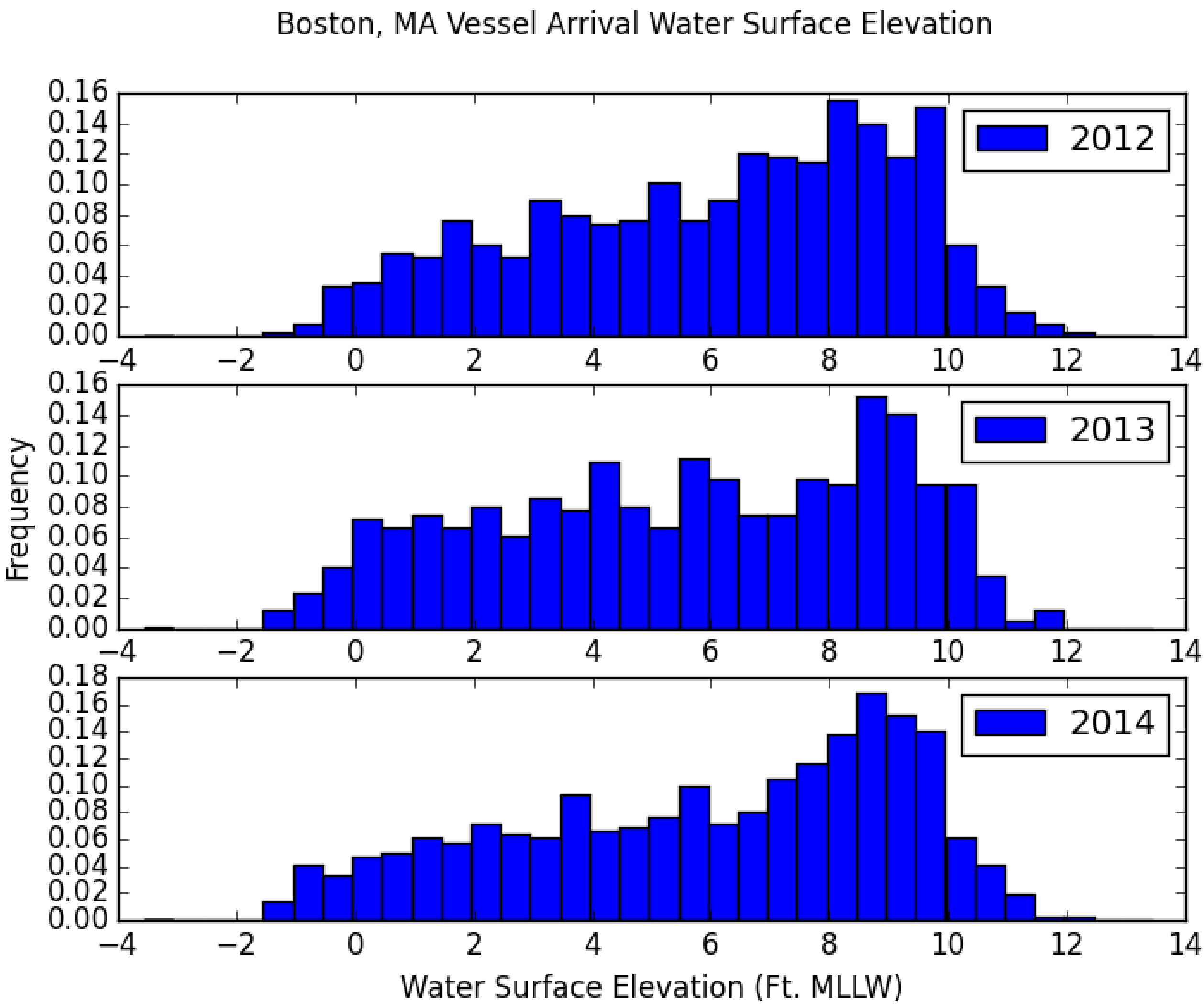



Vessel Call Frequency, Boston, MA, 2012
MON 4 0 1 4 2 5 1 1 8 8 4 5 5 7 9 3 9 5 1 2 1 3 1 3
TUE 1 6 2 2 2 0 1 6 10 13 7 5 4 4 3 4 4 2 7 3 7 2 2 3
WED 1 1 2 2 3 1 1 2 6 9 10 4 5 4 5 5 5 4 3 7 7 3 4 4
THU 2 2 4 1 2 3 3 4 11 11 12 8 4 8 1 2 4 5 7 3 5 2 9 3
FRI 5 7 2 8 1 3 2 3 11 9 13 8 3 9 7 5 9 6 1 6 4 4 5 2
SAT 5 1 3 6 4 4 1 7 7 8 2 6 7 4 4 4 3 2 3 4 3 3 3 3
SUN 0 3 1 4 0 2 1 3 2 11 8 8 2 11 9 3 8 6 3 2 2 1 3 3
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)


Vessel Call Frequency, Boston, MA, 2013
MON 0 1 1 1 0 1 0 0 3 12 8 5 7 8 6 6 3 1 3 7 3 2 2 7
TUE 3 1 1 1 1 1 0 1 6 12 6 7 3 9 10 5 2 5 1 4 2 0 4 3
WED 0 6 1 4 2 1 2 4 5 10 13 10 7 8 8 9 4 4 6 5 4 6 2 3
THU 2 3 5 1 2 2 4 3 7 23 11 8 7 6 6 8 5 4 0 3 2 3 3 6
FRI 4 5 7 4 4 3 4 6 6 7 12 11 6 5 4 8 2 3 0 3 2 2 4 0
SAT 1 2 6 2 2 0 0 4 7 9 10 7 4 5 2 4 6 5 3 4 2 2 2 1
SUN 1 3 1 0 2 2 2 1 4 4 2 5 7 1 5 3 5 5 3 2 9 2 3 0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)


Vessel Call Frequency, Boston, MA, 2014
MON 2 2 5 3 2 0 4 0 11 13 9 6 6 7 8 5 5 1 6 3 7 1 3 3
TUE 2 2 2 1 4 2 5 3 7 14 5 10 7 6 9 3 6 8 5 5 3 2 4 1
WED 1 2 2 2 0 3 1 2 7 9 7 6 7 2 5 3 6 3 2 1 8 2 3 1
THU 1 1 5 3 3 2 2 1 4 13 6 2 10 14 2 4 3 8 5 2 3 6 4 5
FRI 4 5 4 6 2 2 1 4 6 15 7 10 5 5 4 5 6 7 5 2 5 3 2 2
SAT 4 3 3 2 1 2 2 1 5 12 7 6 7 8 3 6 6 4 5 3 4 5 1 3
SUN 1 0 4 1 3 0 2 5 5 7 7 10 8 8 5 3 5 2 3 0 2 0 3 1
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)

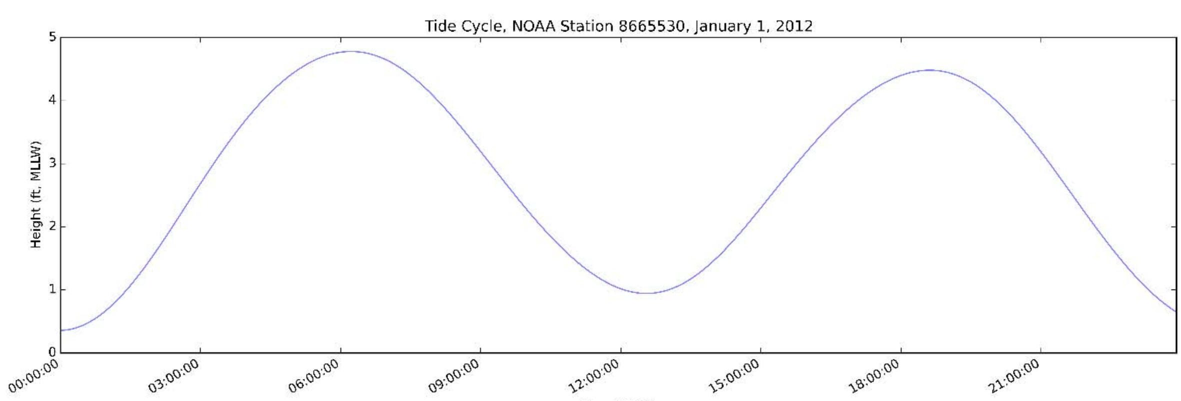

Boston, MA Interarrival Times
2012
2013
2014
Frequency
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0
10
20
30
40
Time Between Arrivals (Hours)

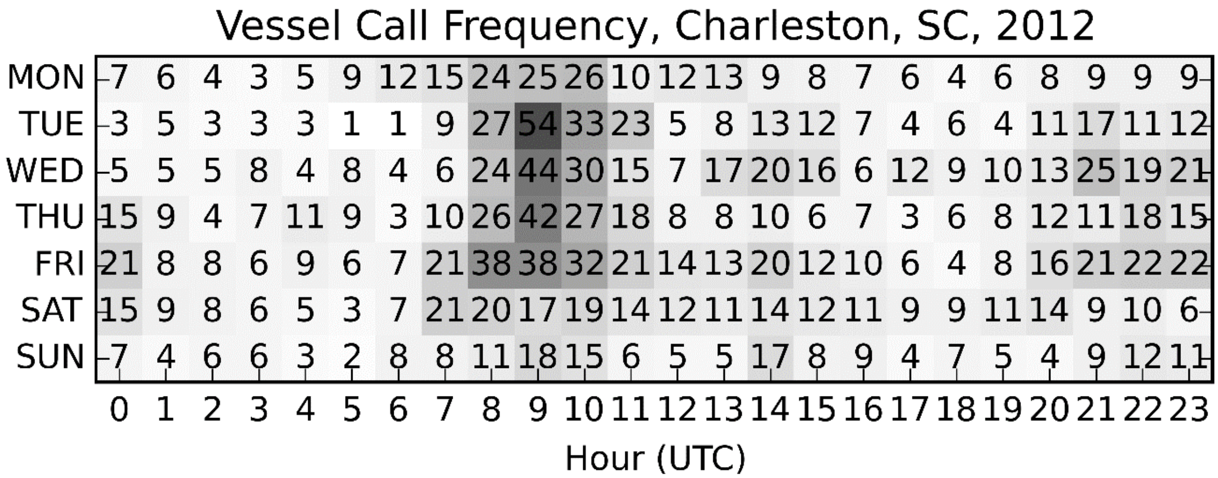

Boston, MA Vessel Arrival Water Surface Elevation
2012
2013
2014
Frequency
Water Surface Elevation (Ft. MLLW)
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
−4
−2
0
2
4
6
8
10
12
14

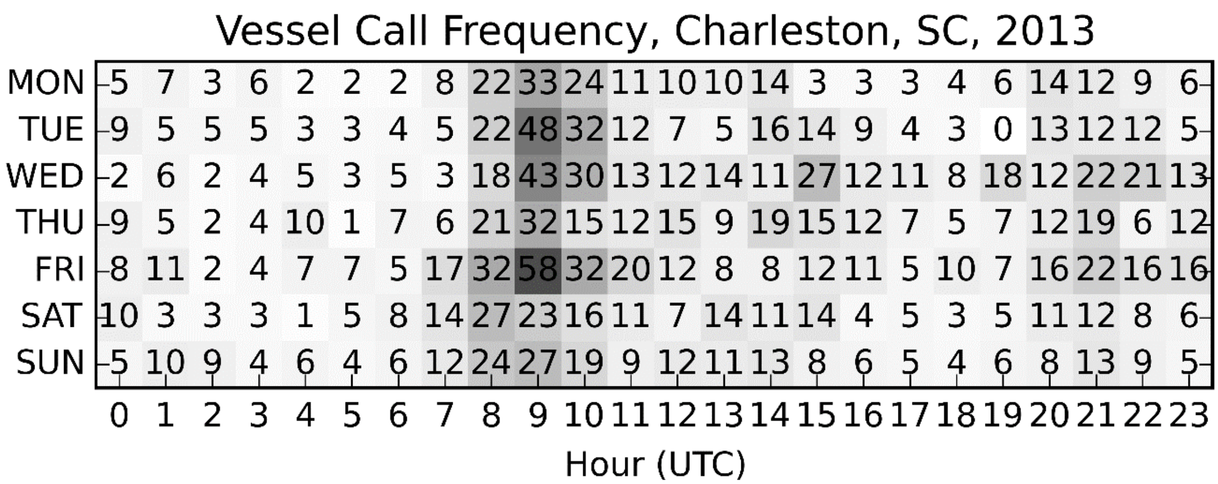
Port of Interest: **Charleston, SC**

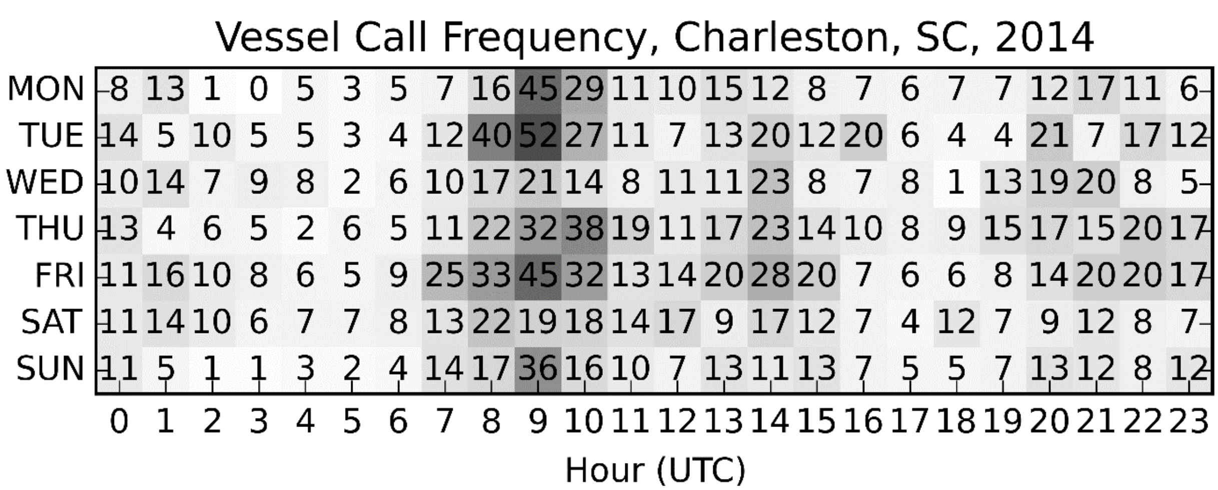
Tide Station Number: 8665530

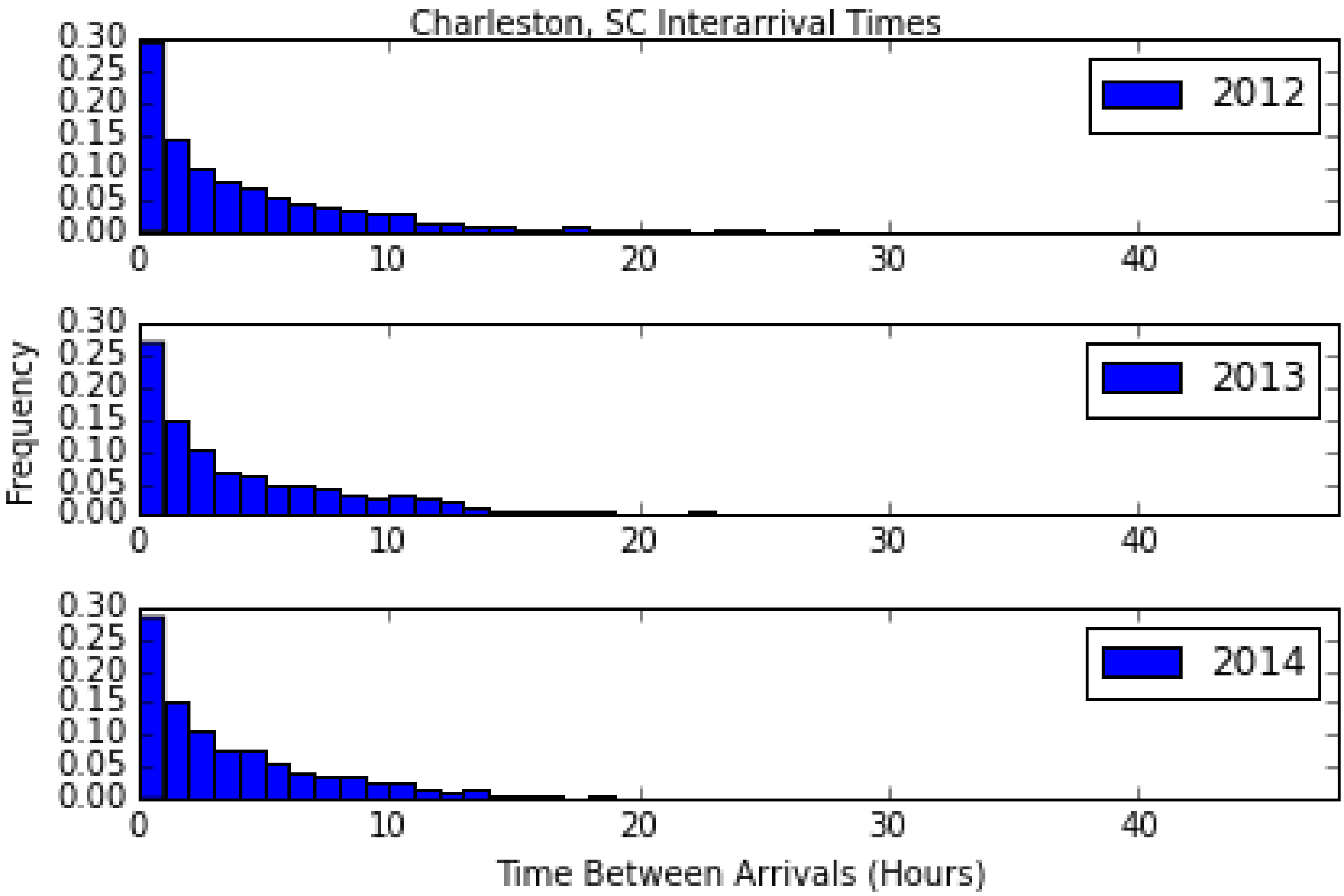
Year	Tide Range (Ft.)	Z_{25} (Ft.)	Z_{75} (Ft.)	T_{25}	T_{50}	T_{75}	TD	Arrivals
2012	8.24	1.13	4.66	0.25	0.48	0.27	0.05	1992
2013	8.17	1.12	4.69	0.26	0.50	0.24	-0.04	1854
2014	8.46	1.10	4.71	0.25	0.49	0.25	0.01	2087



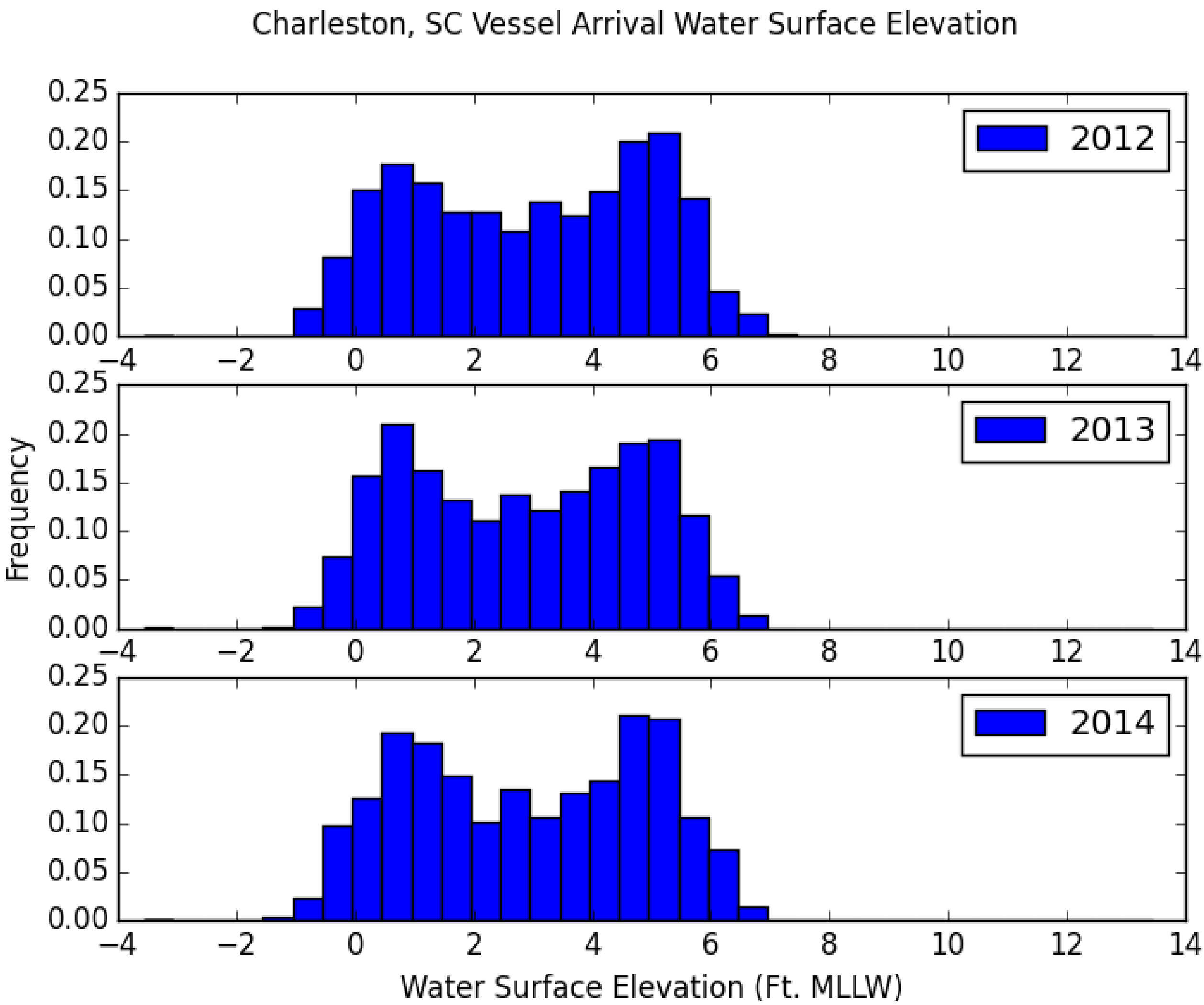

Vessel Call Frequency, Charleston, SC, 2012
MON 7 6 4 3 5 9 12 15 24 25 26 10 12 13 9 8 7 6 4 6 8 9 9 9
TUE 3 5 3 3 3 1 1 9 27 54 33 23 5 8 13 12 7 4 6 4 11 17 11 12
WED 5 5 5 8 4 8 4 6 24 44 30 15 7 17 20 16 6 12 9 10 13 25 19 21
THU 15 9 4 7 11 9 3 10 26 42 27 18 8 8 10 6 7 3 6 8 12 11 18 15
FRI 21 8 8 6 9 6 7 21 38 38 32 21 14 13 20 12 10 6 4 8 16 21 22 22
SAT 15 9 8 6 5 3 7 21 20 17 19 14 12 11 14 12 11 9 9 11 14 9 10 6
SUN 7 4 6 6 3 2 8 8 11 18 15 6 5 5 17 8 9 4 7 5 4 9 12 11
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)


Vessel Call Frequency, Charleston, SC, 2013
MON 5 7 3 6 2 2 2 8 22 33 24 11 10 10 14 3 3 3 4 6 14 12 9 6
TUE 9 5 5 5 3 3 4 5 22 48 32 12 7 5 16 14 9 4 3 0 13 12 12 5
WED 2 6 2 4 5 3 5 3 18 43 30 13 12 14 11 27 12 11 8 18 12 22 21 13
THU 9 5 2 4 10 1 7 6 21 32 15 12 15 9 19 15 12 7 5 7 12 19 6 12
FRI 8 11 2 4 7 7 5 17 32 58 32 20 12 8 8 12 11 5 10 7 16 22 16 16
SAT 10 3 3 3 1 5 8 14 27 23 16 11 7 14 11 14 4 5 3 5 11 12 8 6
SUN 5 10 9 4 6 4 6 12 24 27 19 9 12 11 13 8 6 5 4 6 8 13 9 5
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)

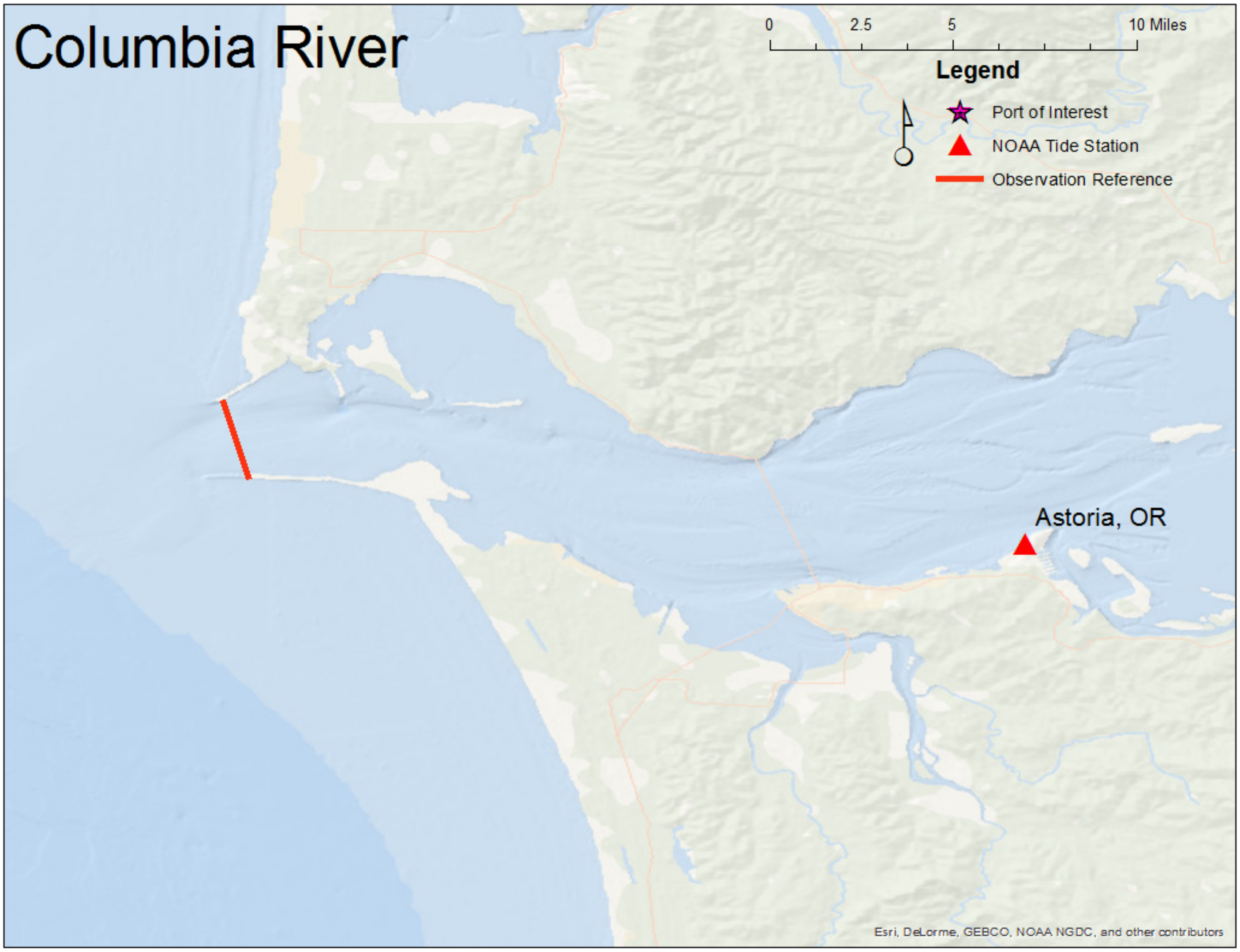

Vessel Call Frequency, Charleston, SC, 2014
MON 8 13 1 0 5 3 5 7 16 45 29 11 10 15 12 8 7 6 7 7 12 17 11 6
TUE 14 5 10 5 5 3 4 12 40 52 27 11 7 13 20 12 20 6 4 4 21 7 17 12
WED 10 14 7 9 8 2 6 10 17 21 14 8 11 11 23 8 7 8 1 13 19 20 8 5
THU 13 4 6 5 2 6 5 11 22 32 38 19 11 17 23 14 10 8 9 15 17 15 20 17
FRI 11 16 10 8 6 5 9 25 33 45 32 13 14 20 28 20 7 6 6 8 14 20 20 17
SAT 11 14 10 6 7 7 8 13 22 19 18 14 17 9 17 12 7 4 12 7 9 12 8 7
SUN 11 5 1 1 3 2 4 14 17 36 16 10 7 13 11 13 7 5 5 7 13 12 8 12
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)



Charleston, SC Interarrival Times
2012
2013
2014
Frequency
Time Between Arrivals (Hours)
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
10
20
30
40



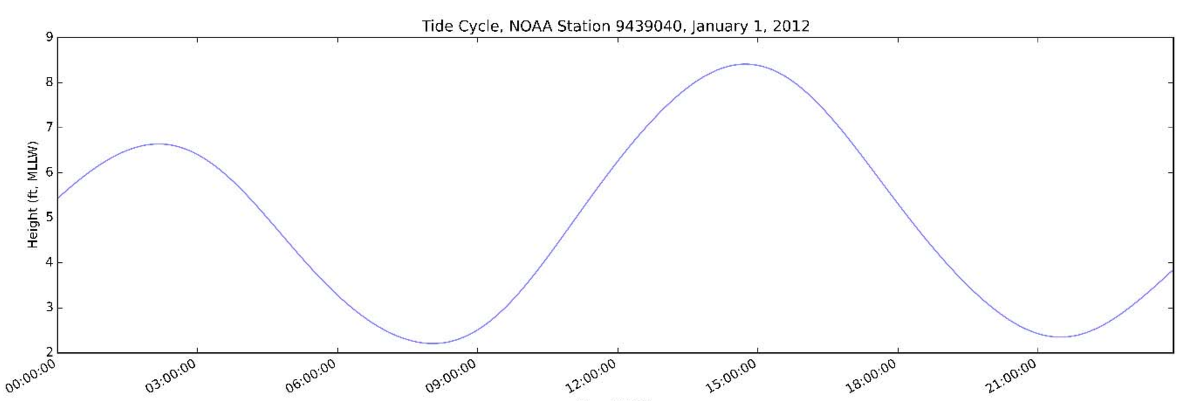
Charleston, SC Vessel Arrival Water Surface Elevation
2012
2013
2014
Frequency
Water Surface Elevation (Ft. MLLW)
0.25
0.20
0.15
0.10
0.05
0.00
−4
−2
0
2
4
6
8
10
12
14

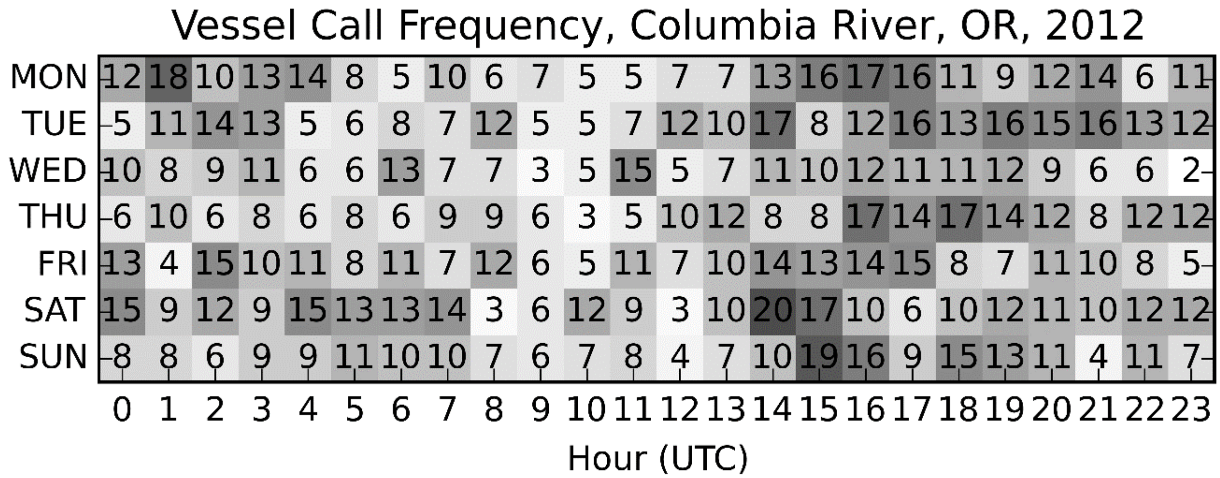


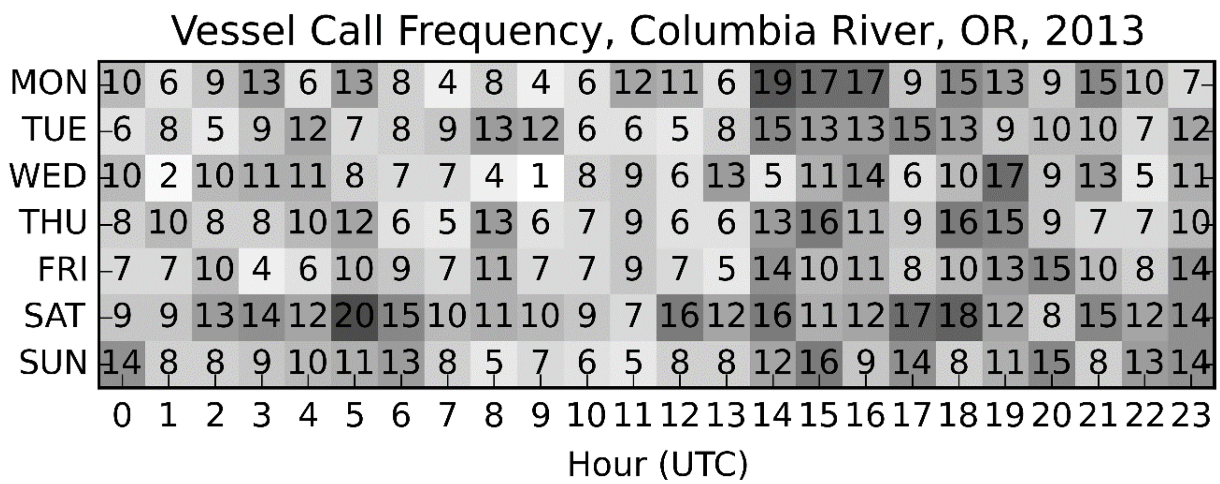
Port of Interest: **Columbia River, OR**

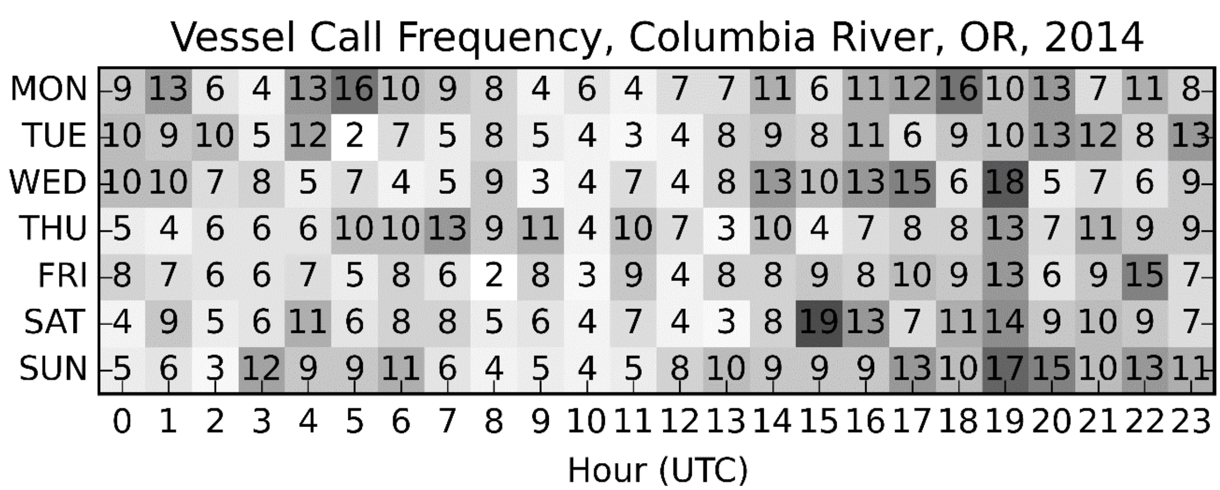
Tide Station Number: 9439040

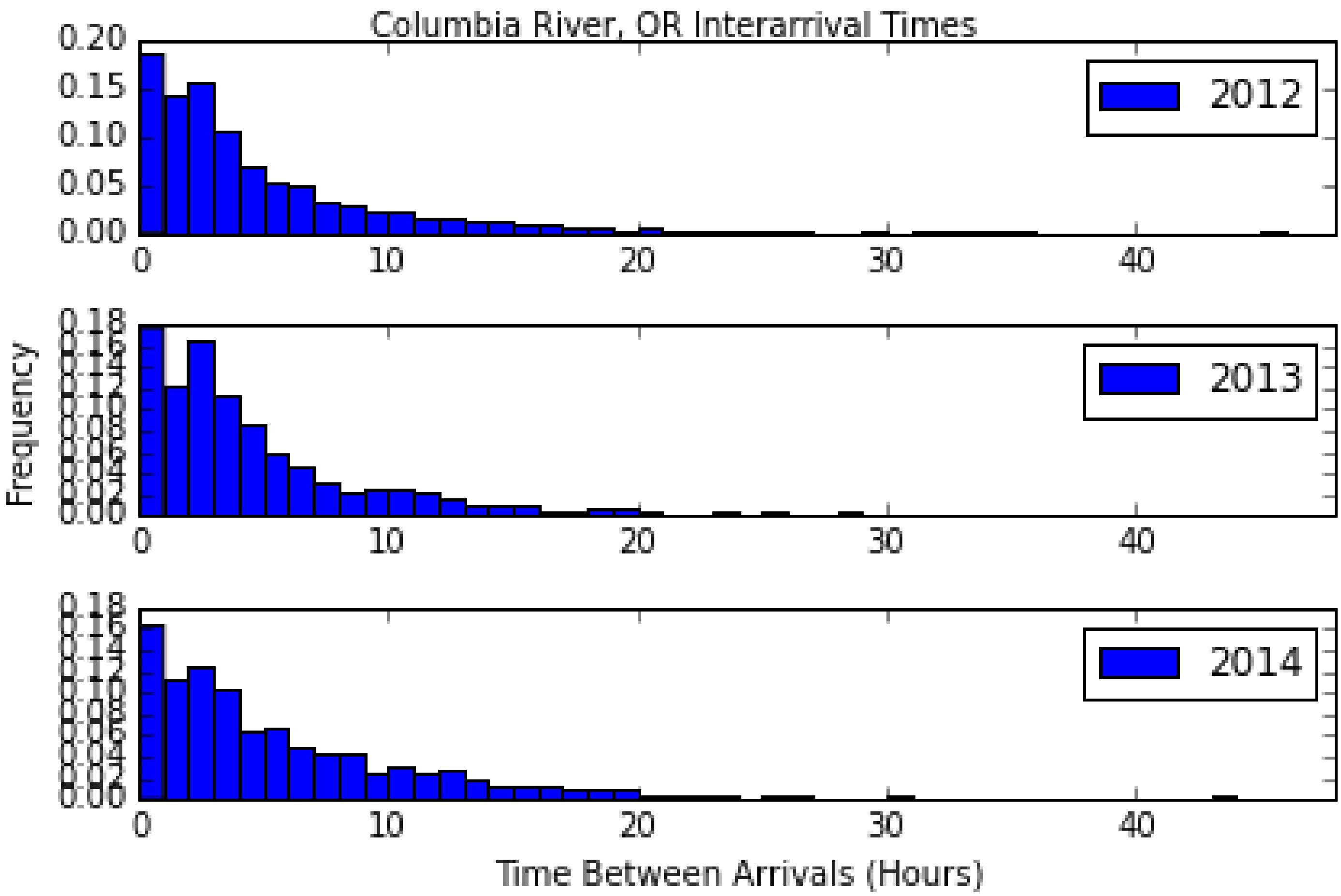
Year	Tide Range (Ft.)	Z_{25} (Ft.)	Z_{75} (Ft.)	T_{25}	T_{50}	T_{75}	TD	Arrivals
2012	12.53	2.43	6.73	0.25	0.53	0.23	-0.04	1661
2013	12.41	2.42	6.73	0.24	0.50	0.25	0.02	1674
2014	12.44	2.41	6.75	0.24	0.52	0.24	0.00	1382

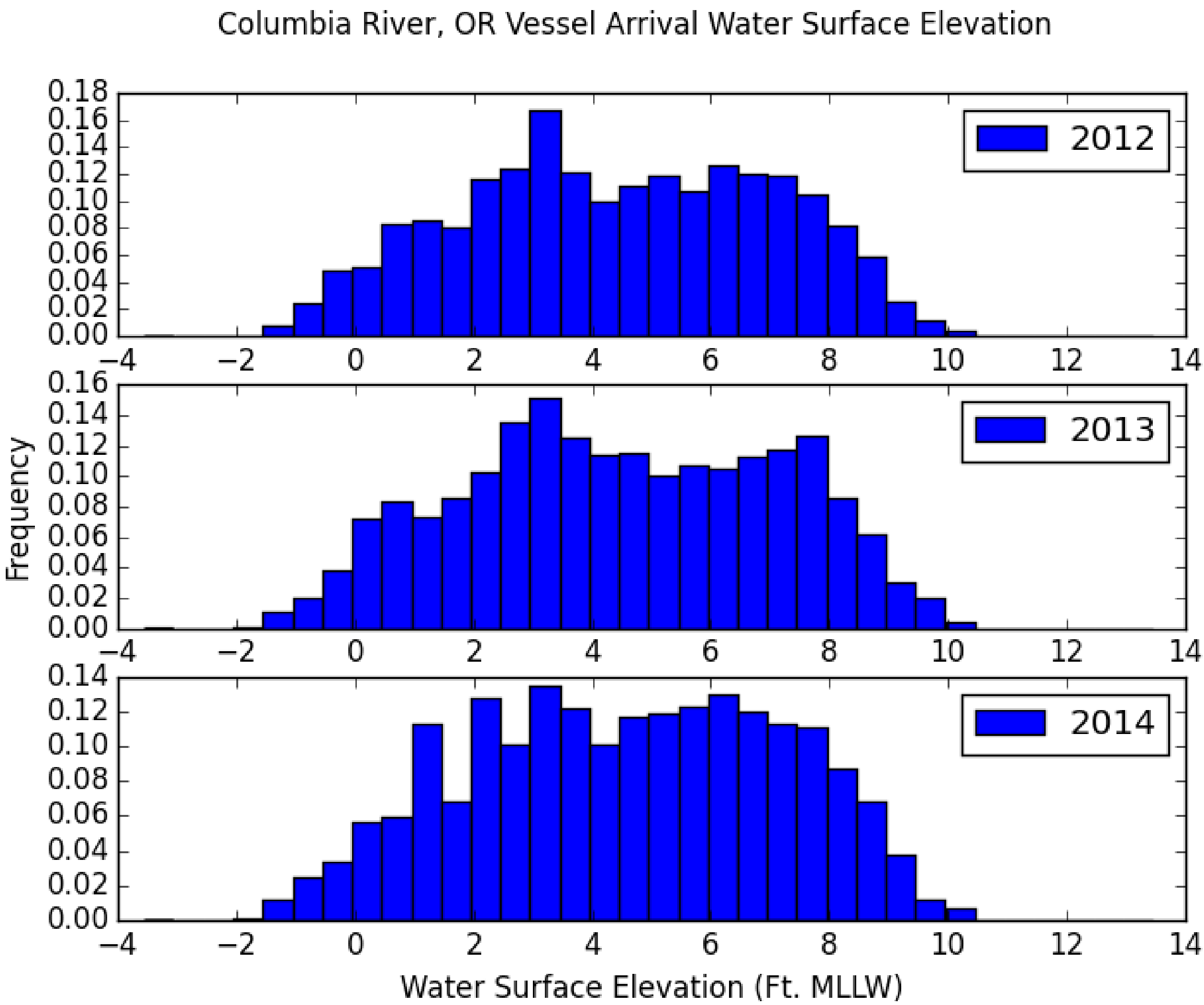


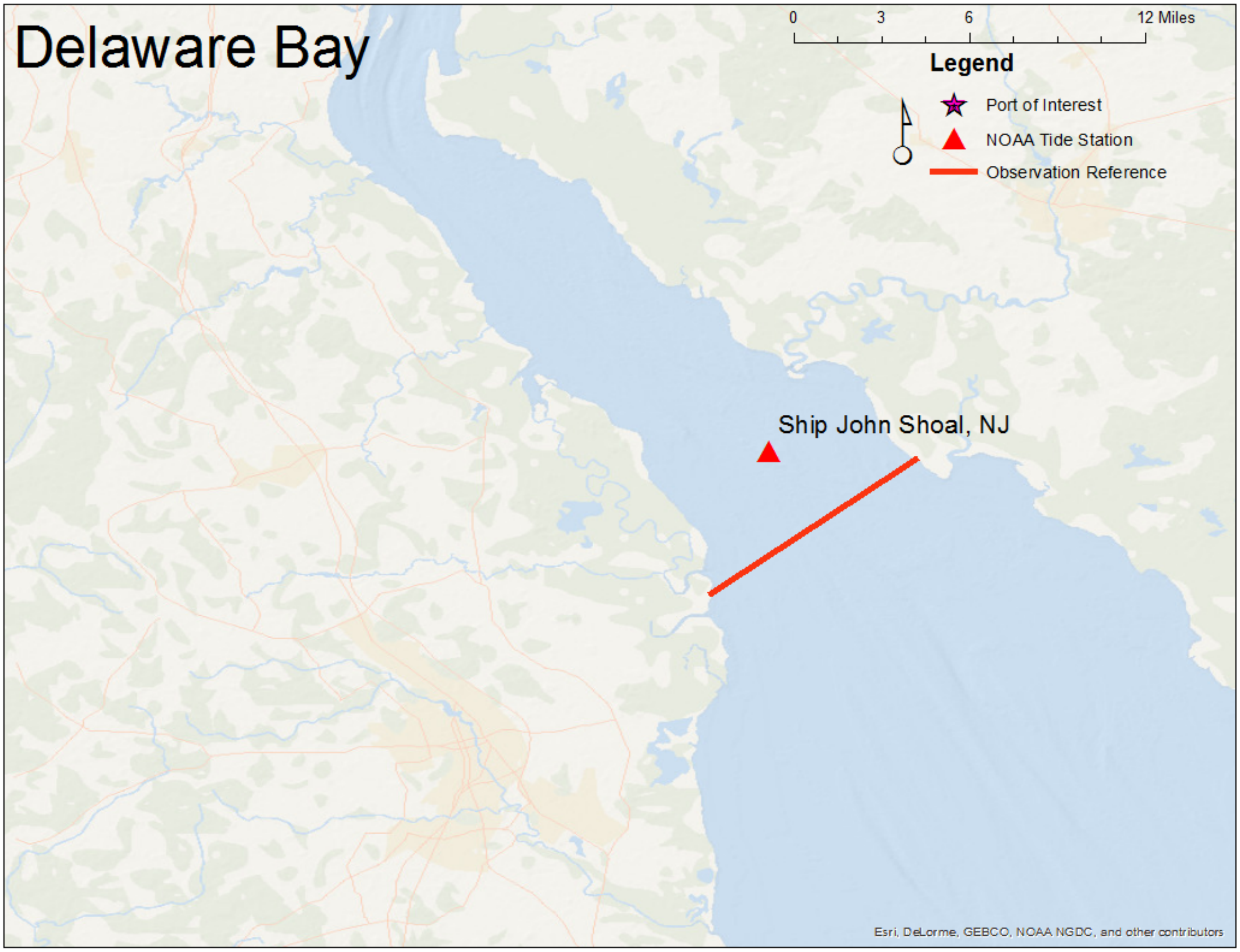

Vessel Call Frequency, Columbia River, OR, 2012
MON 12 18 10 13 14 8 5 10 6 7 5 5 7 7 13 16 17 16 11 9 12 14 6 11
TUE 5 11 14 13 5 6 8 7 12 5 5 7 12 10 17 8 12 16 13 16 15 16 13 12
WED 10 8 9 11 6 6 13 7 7 3 5 15 5 7 11 10 12 11 11 12 9 6 6 2
THU 6 10 6 8 6 8 6 9 9 6 3 5 10 12 8 8 17 14 17 14 12 8 12 12
FRI 13 4 15 10 11 8 11 7 12 6 5 11 7 10 14 13 14 15 8 7 11 10 8 5
SAT 15 9 12 9 15 13 13 14 3 6 12 9 3 10 20 17 10 6 10 12 11 10 12 12
SUN 8 8 6 9 9 11 10 10 7 6 7 8 4 7 10 19 16 9 15 13 11 4 11 7
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)


Vessel Call Frequency, Columbia River, OR, 2013
MON 10 6 9 13 6 13 8 4 8 4 6 12 11 6 19 17 17 9 15 13 9 15 10 7
TUE 6 8 5 9 12 7 8 9 13 12 6 6 5 8 15 13 13 15 13 9 10 10 7 12
WED 10 2 10 11 11 8 7 7 4 1 8 9 6 13 5 11 14 6 10 17 9 13 5 11
THU 8 10 8 8 10 12 6 5 13 6 7 9 6 6 13 16 11 9 16 15 9 7 7 10
FRI 7 7 10 4 6 10 9 7 11 7 7 9 7 5 14 10 11 8 10 13 15 10 8 14
SAT 9 9 13 14 12 20 15 10 11 10 9 7 16 12 16 11 12 17 18 12 8 15 12 14
SUN 14 8 8 9 10 11 13 8 5 7 6 5 8 8 12 16 9 14 8 11 15 8 13 14
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)


Vessel Call Frequency, Columbia River, OR, 2014
MON 9 13 6 4 13 16 10 9 8 4 6 4 7 7 11 6 11 12 16 10 13 7 11 8
TUE 10 9 10 5 12 2 7 5 8 5 4 3 4 8 9 8 11 6 9 10 13 12 8 13
WED 10 10 7 8 5 7 4 5 9 3 4 7 4 8 13 10 13 15 6 18 5 7 6 9
THU 5 4 6 6 6 10 10 13 9 11 4 10 7 3 10 4 7 8 8 13 7 11 9 9
FRI 8 7 6 6 7 5 8 6 2 8 3 9 4 8 8 9 8 10 9 13 6 9 15 7
SAT 4 9 5 6 11 6 8 8 5 6 4 7 4 3 8 19 13 7 11 14 9 10 9 7
SUN 5 6 3 12 9 9 11 6 4 5 4 5 8 10 9 9 9 13 10 17 15 10 13 11
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)


Columbia River, OR Interarrival Times
2012
2013
2014
Frequency
Time Between Arrivals (Hours)
0.20
0.15
0.10
0.05
0.00
0.18
0
10
20
30
40

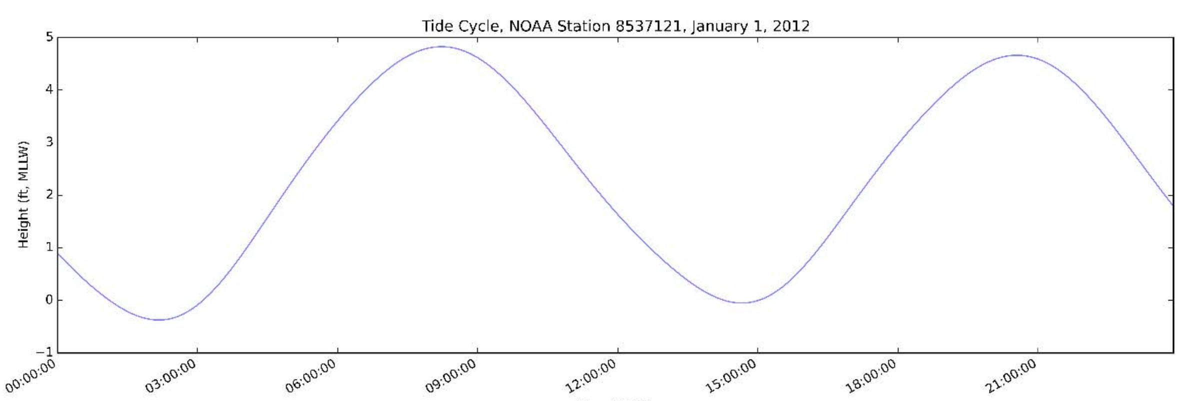

Columbia River, OR Vessel Arrival Water Surface Elevation
Frequency
2012
2013
2014
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
−4
−2
0
2
4
6
8
10
12
14
Water Surface Elevation (Ft. MLLW)



Port of Interest: **Delaware Bay**

Tide Station Number: 8537121

Year	Tide Range (Ft.)	Z_{25} (Ft.)	Z_{75} (Ft.)	T_{25}	T_{50}	T_{75}	TD	Arrivals
2012	8.76	1.08	4.91	0.25	0.49	0.26	0.03	1744
2013	8.95	1.07	4.92	0.21	0.50	0.29	0.16	2427
2014	8.89	1.07	4.94	0.23	0.50	0.28	0.10	2313



Vessel Call Frequency, Delaware Bay, 2012

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
MON	13	13	21	22	21	17	16	17	12	6	9	11	8	8	11	13	8	11	11	11	8	13	17	8
TUE	10	4	8	4	14	23	23	16	43	18	11	9	14	11	13	12	13	13	11	7	10	6	8	6
WED	6	6	9	5	6	12	13	7	11	8	9	4	14	7	6	4	11	12	11	13	11	5	13	5
THU	10	5	7	5	6	6	5	6	9	10	9	9	8	10	6	8	13	16	18	12	7	10	14	10
FRI	13	5	9	6	10	6	11	10	10	5	6	7	8	7	7	10	7	9	9	13	6	10	6	5
SAT	6	5	8	6	7	7	5	5	9	9	8	6	13	4	8	8	7	7	14	9	3	6	8	4
SUN	7	2	6	3	16	31	29	25	15	6	6	14	11	14	10	13	11	17	22	22	22	11	15	10

Hour (UTC)

Vessel Call Frequency, Delaware Bay, 2013

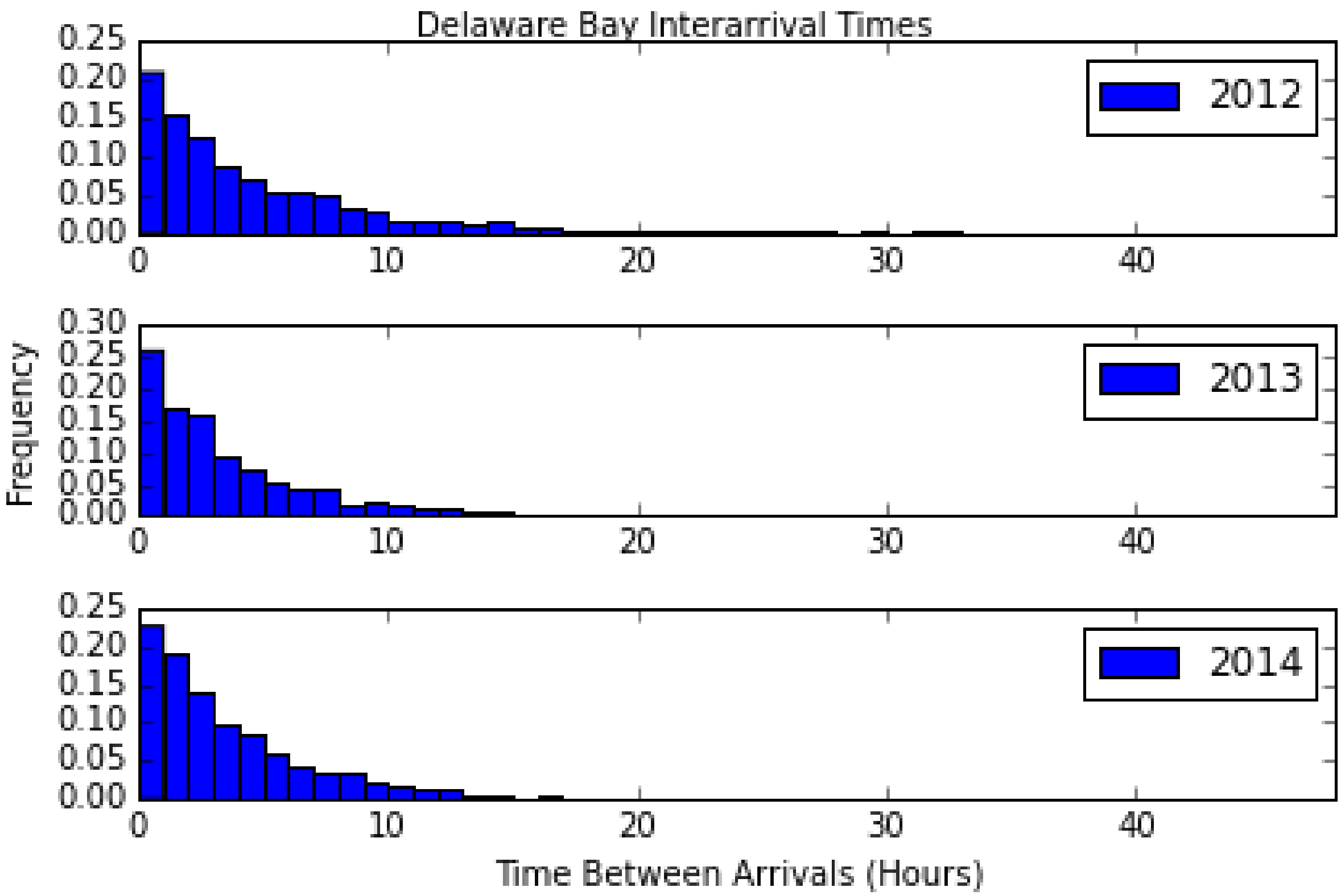
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
MON	23	25	16	29	33	24	23	19	14	13	13	22	12	17	12	18	17	14	12	12	19	13	14	7
TUE	11	10	11	16	10	39	37	22	50	20	15	18	14	13	14	9	14	12	17	14	13	13	13	15
WED	11	11	10	8	9	14	19	12	9	10	16	15	9	7	18	12	11	18	5	14	13	15	16	12
THU	13	5	15	12	6	20	18	14	6	7	6	10	11	10	6	14	12	22	20	19	18	14	13	14
FRI	4	14	13	6	15	16	19	11	11	19	12	12	10	9	13	10	13	13	9	14	16	7	10	5
SAT	8	11	9	11	11	17	14	13	10	12	8	18	18	8	10	9	9	19	10	9	11	12	6	17
SUN	11	10	13	14	9	23	31	19	17	10	14	17	12	19	16	15	18	14	22	23	22	24	34	19

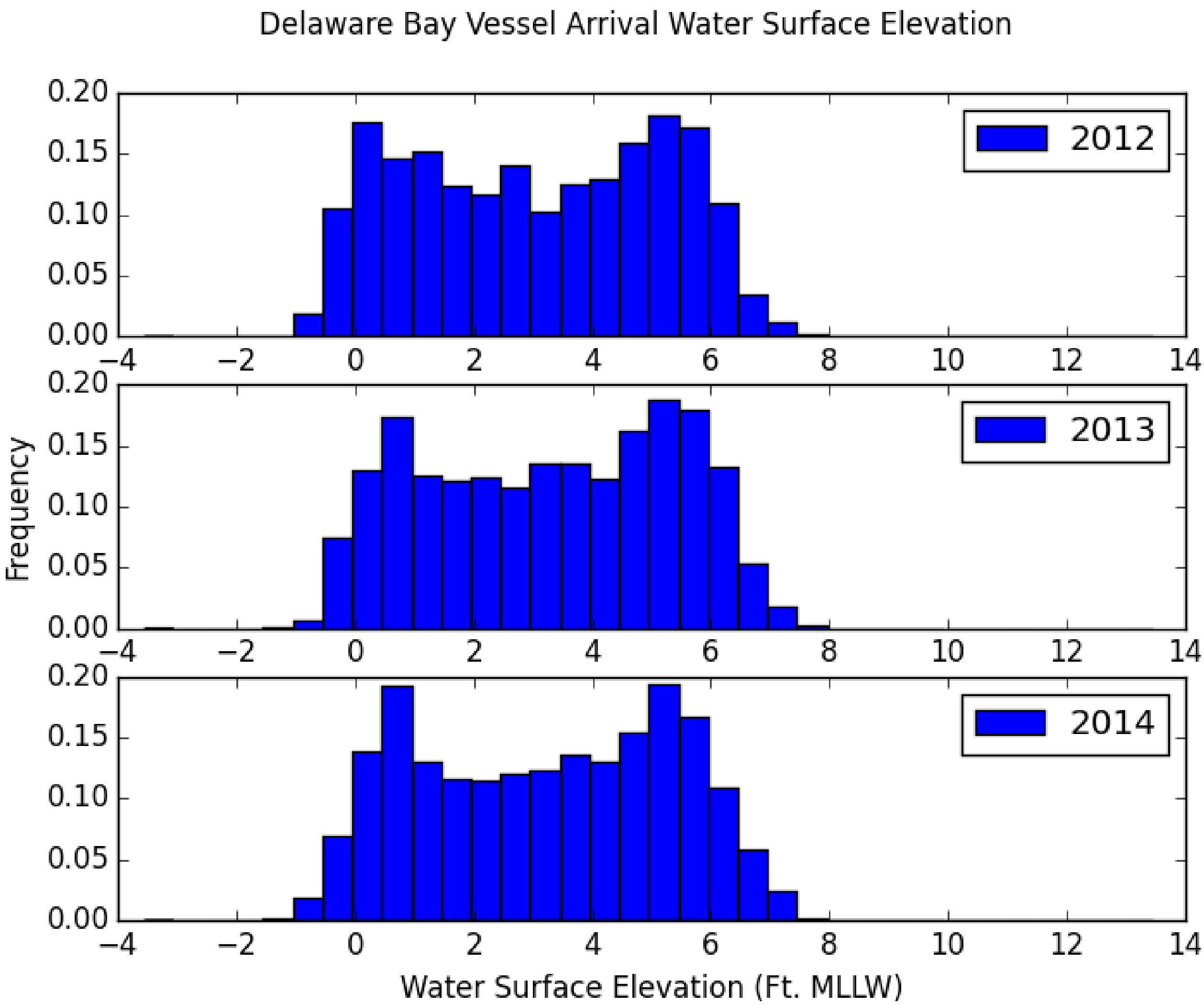
Hour (UTC)

Vessel Call Frequency, Delaware Bay, 2014

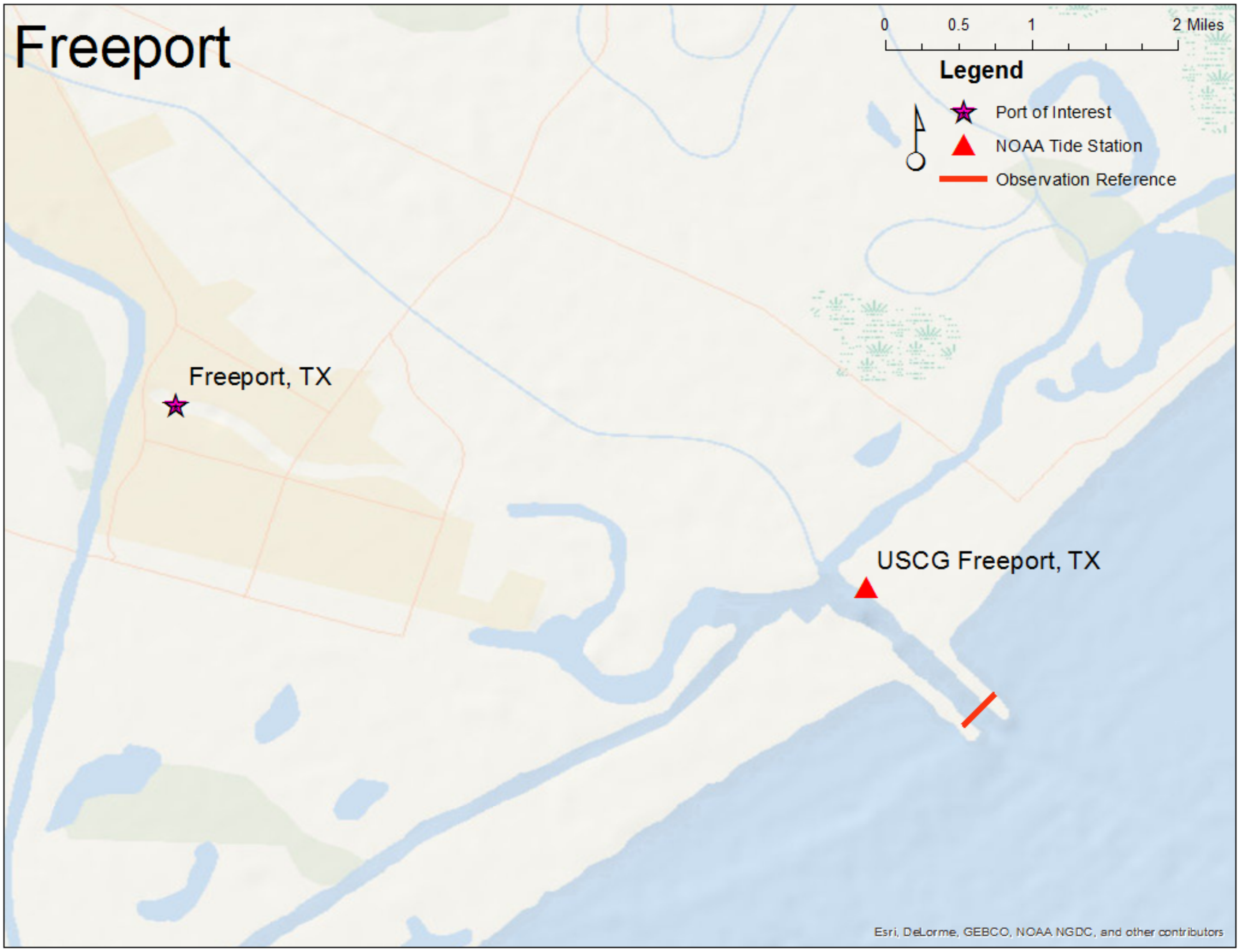
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
MON	18	15	19	15	26	27	17	27	10	18	12	13	19	15	10	18	9	14	17	11	13	13	10	15
TUE	10	13	12	17	19	34	40	17	27	20	14	14	12	16	11	18	16	14	15	10	8	13	16	14
WED	9	13	12	15	14	14	16	13	20	6	5	11	10	10	8	14	11	16	9	20	5	19	13	17
THU	9	13	15	9	10	11	5	12	5	14	4	14	9	14	18	14	8	14	8	23	14	8	10	23
FRI	11	13	11	6	12	31	45	25	14	6	5	11	14	11	8	13	11	10	8	14	10	17	10	12
SAT	8	10	5	14	17	17	11	9	7	6	13	12	8	11	13	12	13	7	9	11	10	10	10	11
SUN	5	11	12	8	10	20	18	20	20	11	9	13	15	13	15	21	14	21	18	18	22	21	17	14

Hour (UTC)


Delaware Bay Interarrival Times
0.25
0.20
0.15
0.10
0.05
0.00
0
10
20
30
40
2012
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Frequency
2013
0.25
0.20
0.15
0.10
0.05
0.00
2014
Time Between Arrivals (Hours)

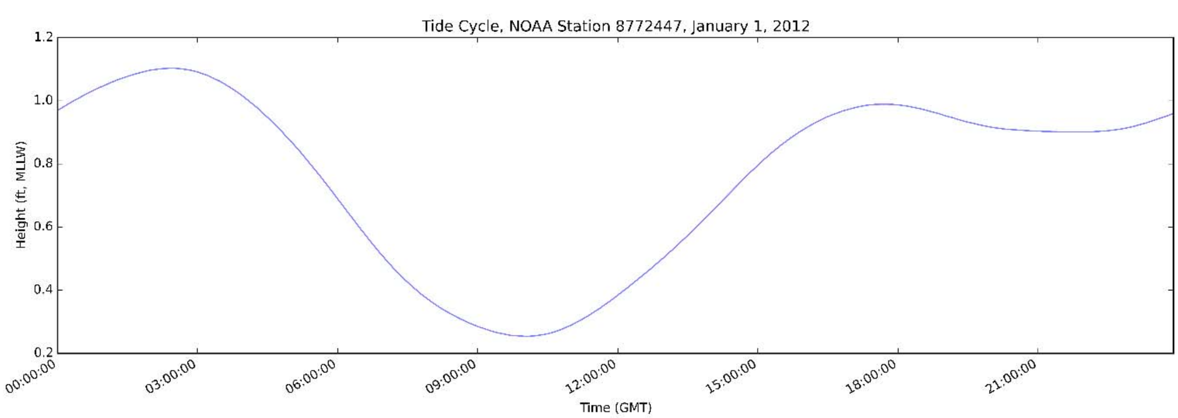


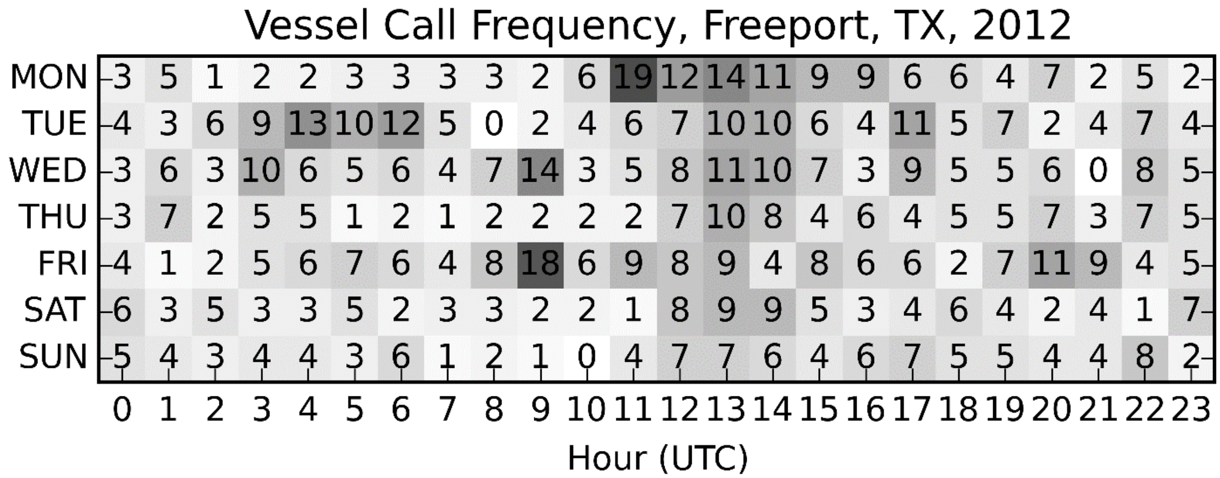
Delaware Bay Vessel Arrival Water Surface Elevation
2012
2013
2014
Frequency
0.20
0.15
0.10
0.05
0.00
−4
−2
0
2
4
6
8
10
12
14
Water Surface Elevation (Ft. MLLW)

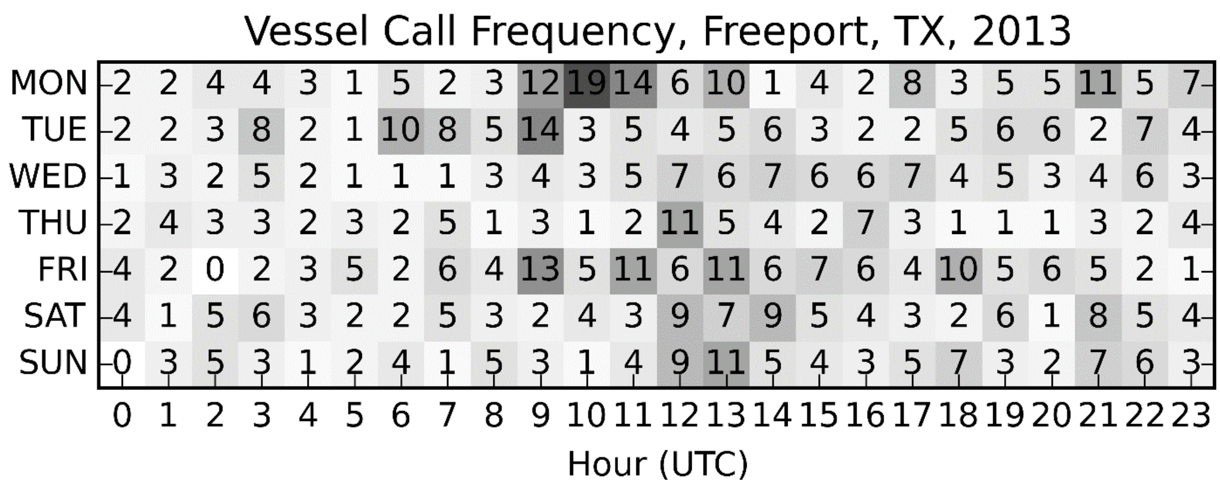


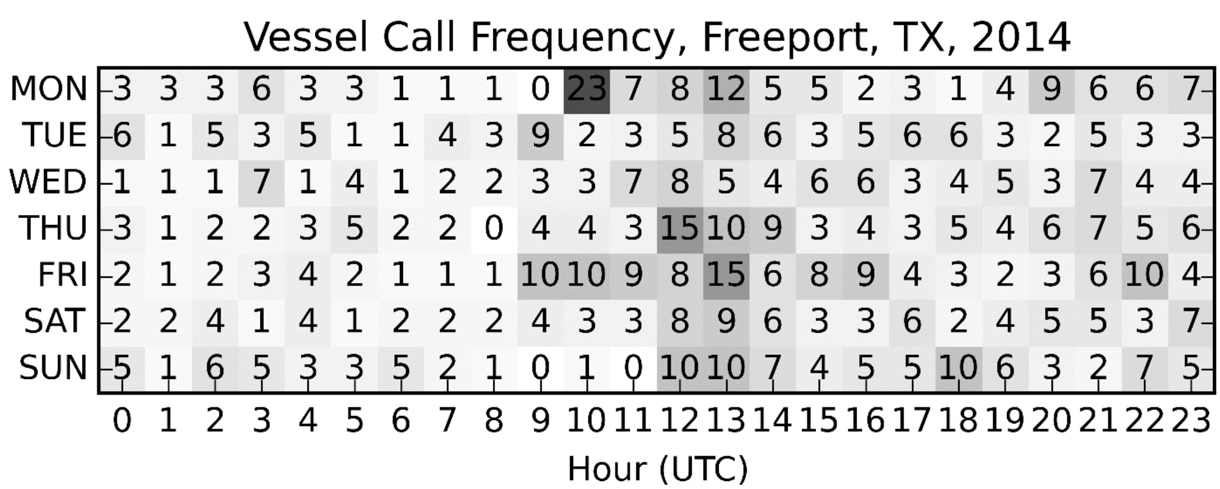
Port of Interest: **Freeport, TX**
Tide Station Number: 8772447

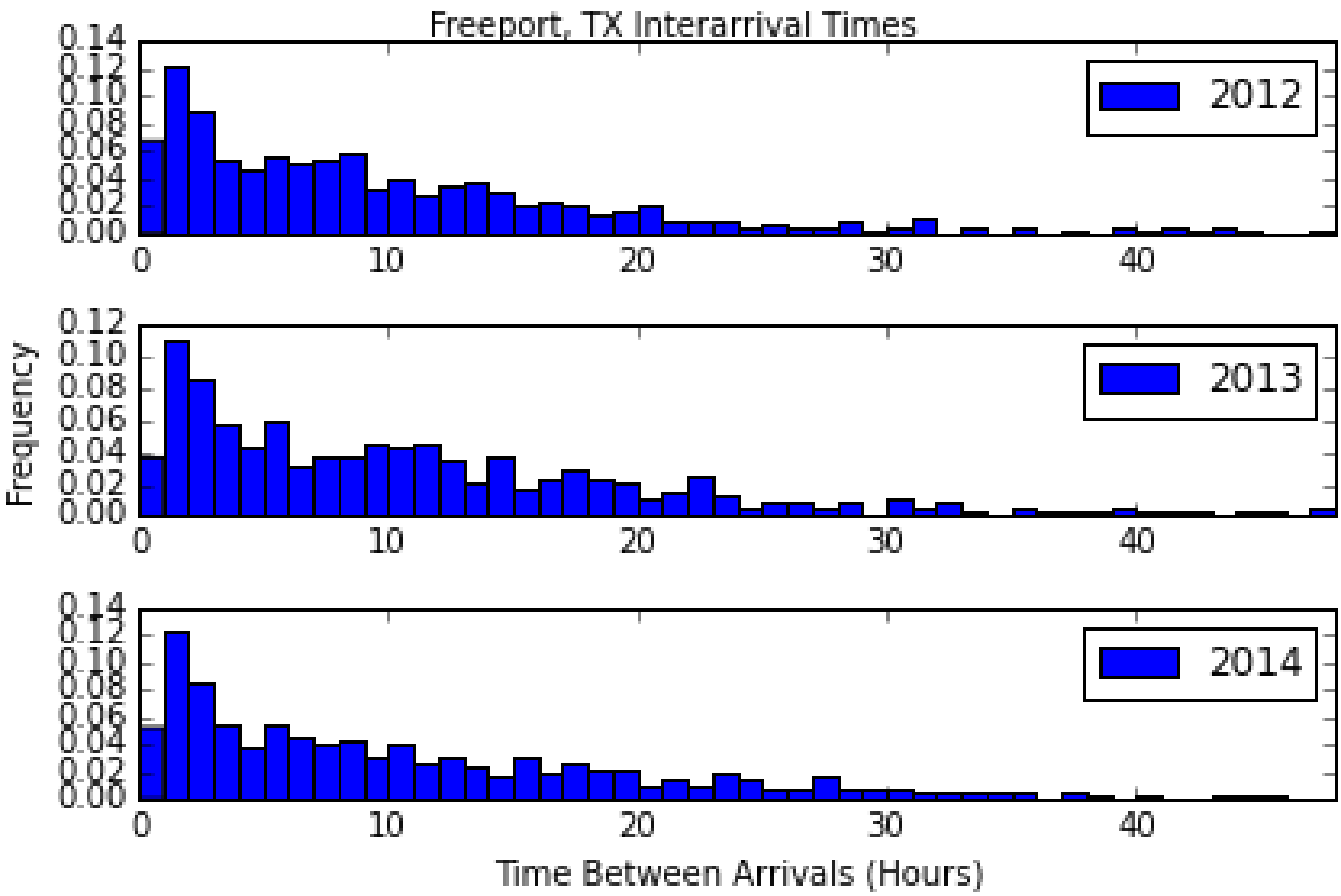
Year	Tide Range (Ft.)	Z_{25} (Ft.)	Z_{75} (Ft.)	T_{25}	T_{50}	T_{75}	TD	Arrivals
2012	3.17	0.59	1.39	0.23	0.50	0.27	0.10	901
2013	3.16	0.61	1.37	0.23	0.51	0.26	0.06	749
2014	3.02	0.62	1.36	0.24	0.50	0.27	0.07	741




Vessel Call Frequency, Freeport, TX, 2012
MON 3 5 1 2 2 3 3 3 3 2 6 19 12 14 11 9 9 6 6 4 7 2 5 2
TUE 4 3 6 9 13 10 12 5 0 2 4 6 7 10 10 6 4 11 5 7 2 4 7 4
WED 3 6 3 10 6 5 6 4 7 14 3 5 8 11 10 7 3 9 5 5 6 0 8 5
THU 3 7 2 5 5 1 2 1 2 2 2 2 7 10 8 4 6 4 5 5 7 3 7 5
FRI 4 1 2 5 6 7 6 4 8 18 6 9 8 9 4 8 6 6 2 7 11 9 4 5
SAT 6 3 5 3 3 5 2 3 3 2 2 1 8 9 9 5 3 4 6 4 2 4 1 7
SUN 5 4 3 4 4 3 6 1 2 1 0 4 7 7 6 4 6 7 5 5 4 4 8 2
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)

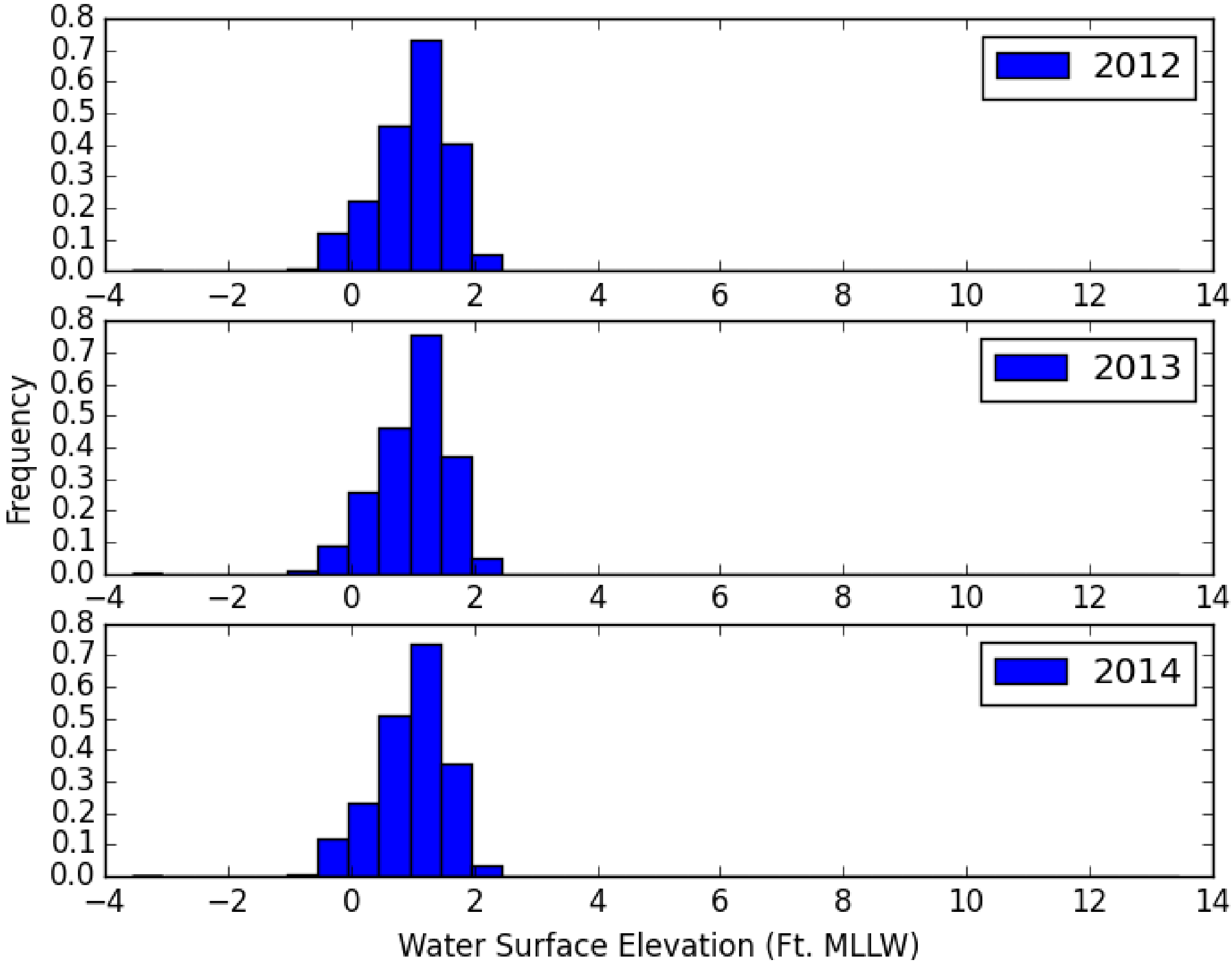

Vessel Call Frequency, Freeport, TX, 2013
MON 2 2 4 4 3 1 5 2 3 12 19 14 6 10 1 4 2 8 3 5 5 11 5 7
TUE 2 2 3 8 2 1 10 8 5 14 3 5 4 5 6 3 2 2 5 6 6 2 7 4
WED 1 3 2 5 2 1 1 1 3 4 3 5 7 6 7 6 6 7 4 5 3 4 6 3
THU 2 4 3 3 2 3 2 5 1 3 1 2 11 5 4 2 7 3 1 1 1 3 2 4
FRI 4 2 0 2 3 5 2 6 4 13 5 11 6 11 6 7 6 4 10 5 6 5 2 1
SAT 4 1 5 6 3 2 2 5 3 2 4 3 9 7 9 5 4 3 2 6 1 8 5 4
SUN 0 3 5 3 1 2 4 1 5 3 1 4 9 11 5 4 3 5 7 3 2 7 6 3
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)

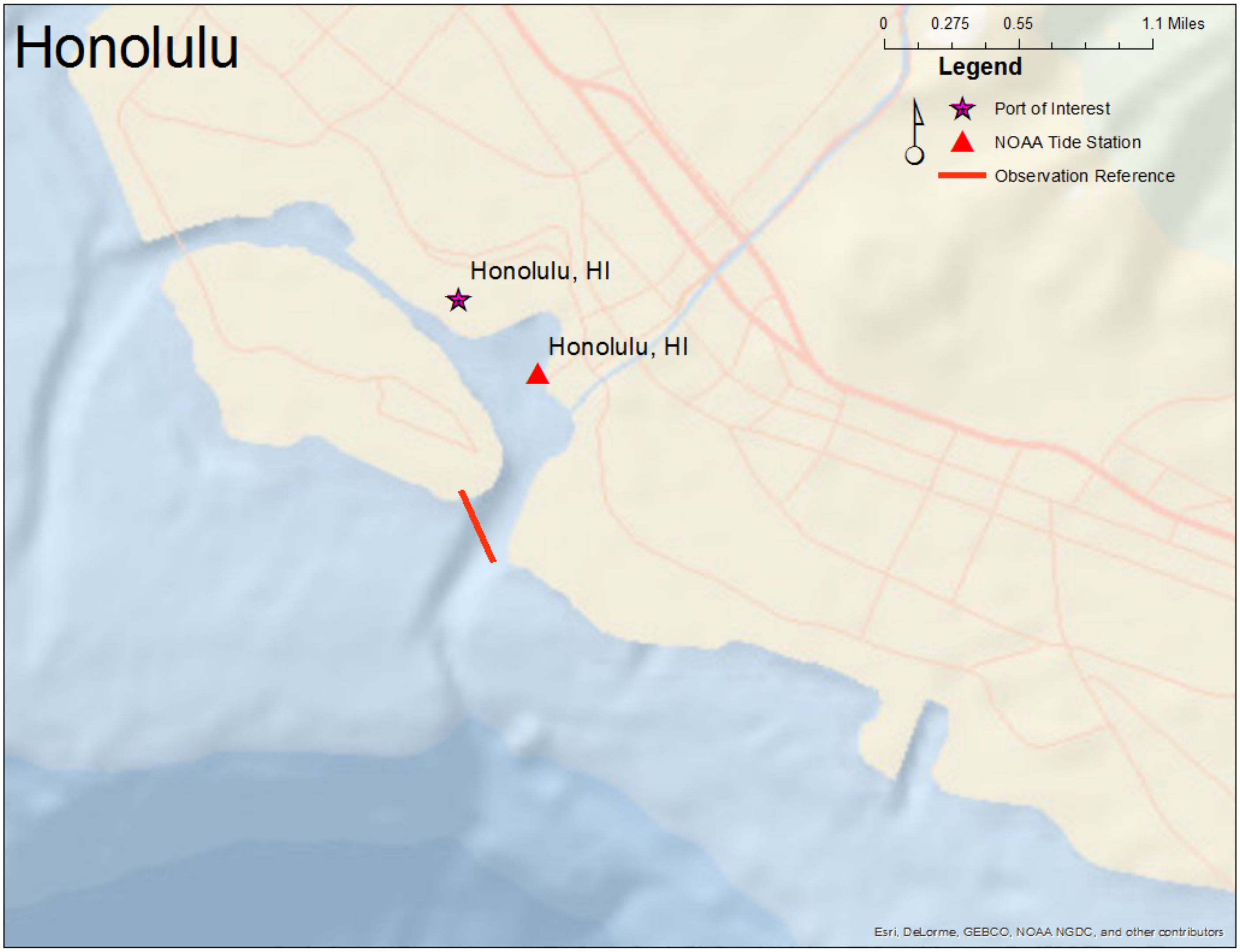

Vessel Call Frequency, Freeport, TX, 2014
MON 3 3 3 6 3 3 1 1 1 0 23 7 8 12 5 5 2 3 1 4 9 6 6 7
TUE 6 1 5 3 5 1 1 4 3 9 2 3 5 8 6 3 5 6 6 3 2 5 3 3
WED 1 1 1 7 1 4 1 2 2 3 3 7 8 5 4 6 6 3 4 5 3 7 4 4
THU 3 1 2 2 3 5 2 2 0 4 4 3 15 10 9 3 4 3 5 4 6 7 5 6
FRI 2 1 2 3 4 2 1 1 1 10 10 9 8 15 6 8 9 4 3 2 3 6 10 4
SAT 2 2 4 1 4 1 2 2 2 4 3 3 8 9 6 3 3 6 2 4 5 5 3 7
SUN 5 1 6 5 3 3 5 2 1 0 1 0 10 10 7 4 5 5 10 6 3 2 7 5
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)



Freeport, TX Interarrival Times
2012
2013
2014
Frequency
Time Between Arrivals (Hours)
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0
10
20
30
40

Freeport, TX Vessel Arrival Water Surface Elevation

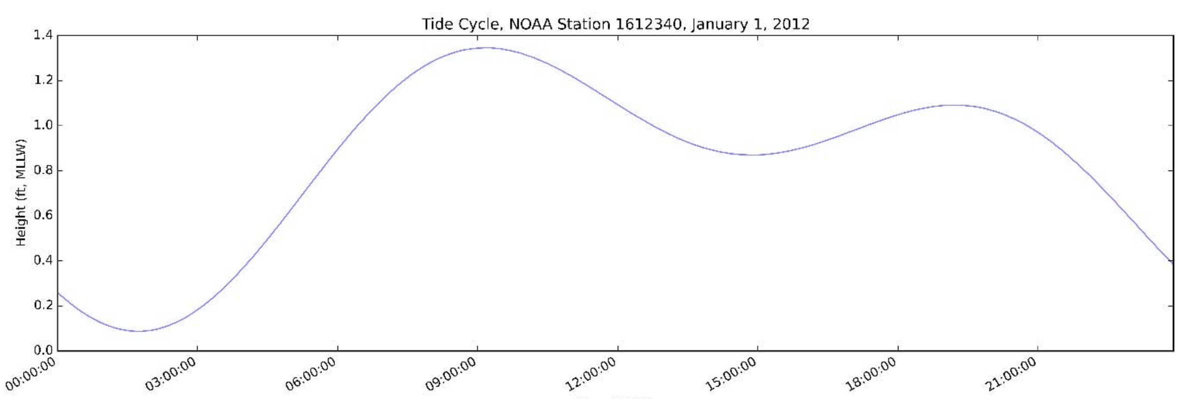


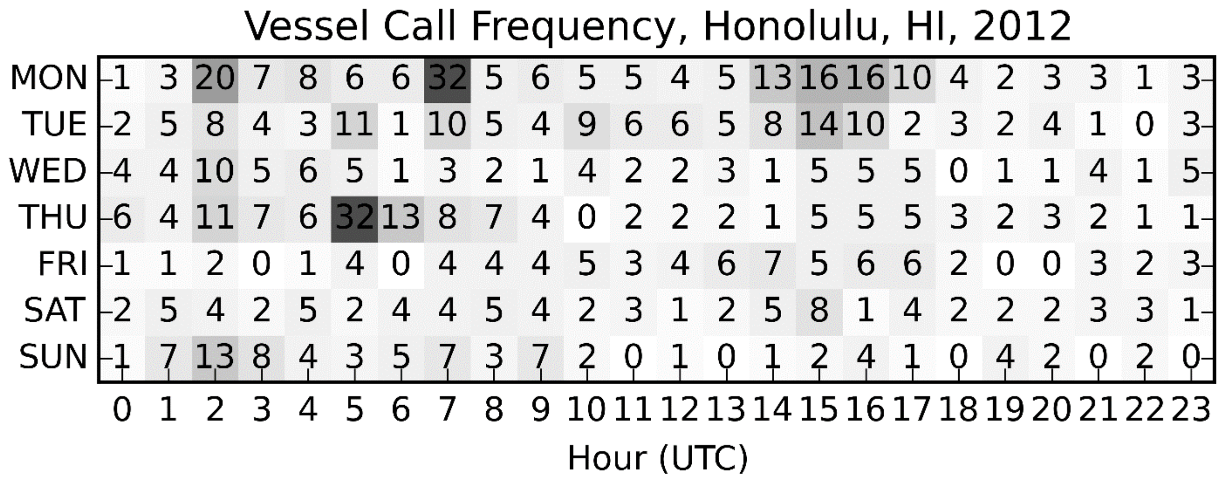


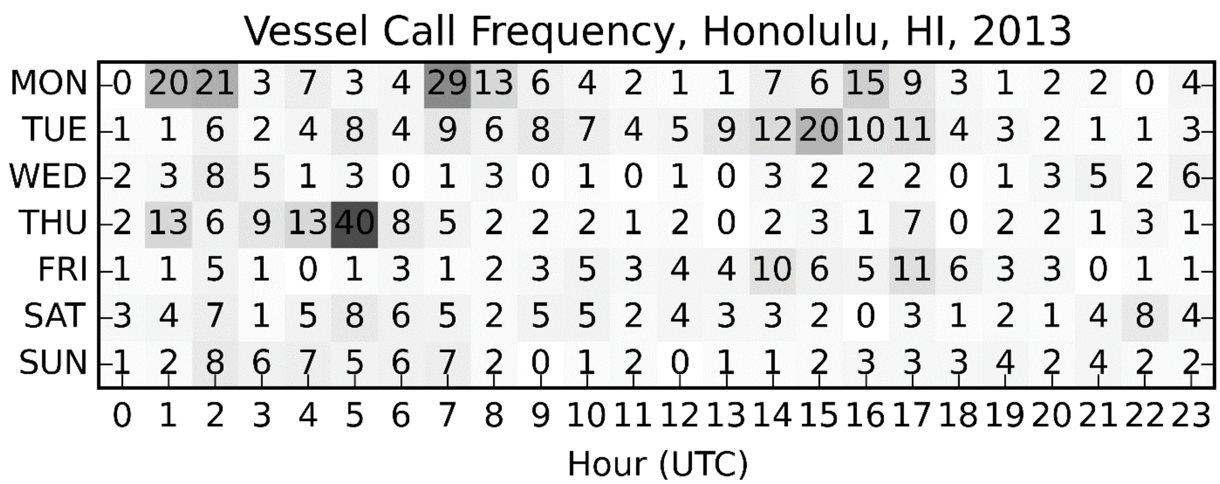
Port of Interest: **Honolulu, HI**

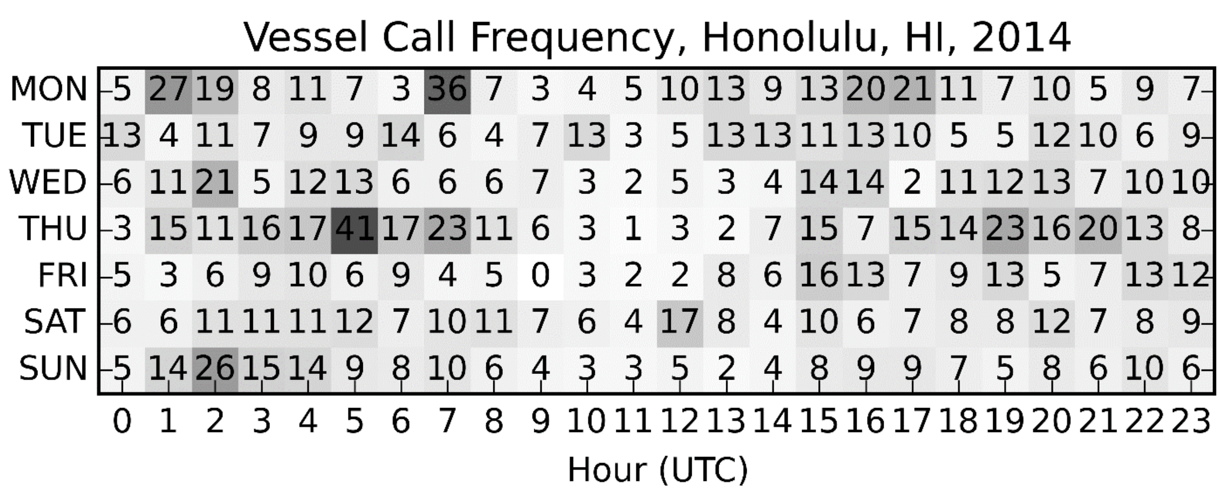
Tide Station Number: 1612340

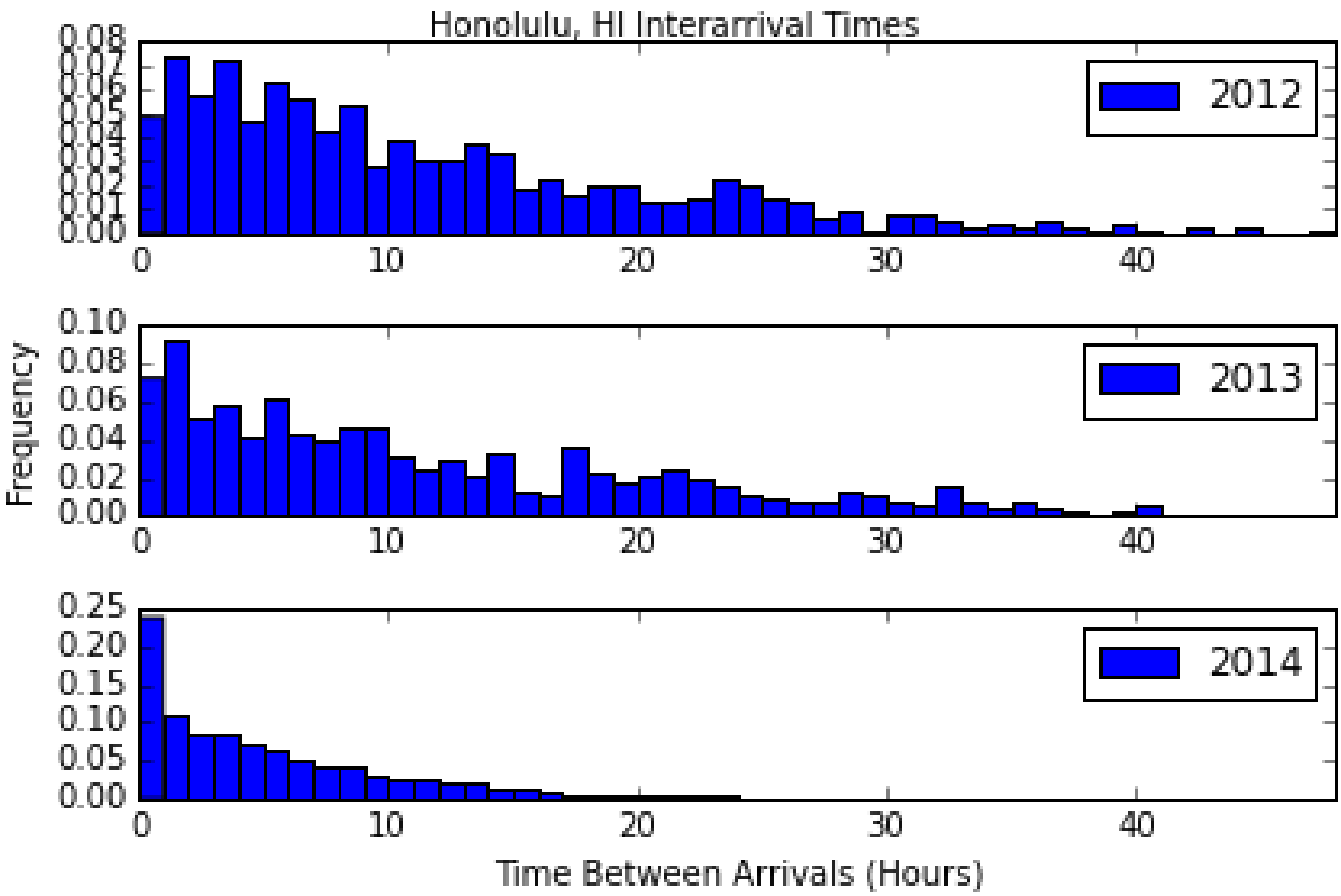
Year	Tide Range (Ft.)	Z_{25} (Ft.)	Z_{75} (Ft.)	T_{25}	T_{50}	T_{75}	TD	Arrivals
2012	3.21	0.35	1.25	0.24	0.48	0.28	0.09	748
2013	3.10	0.36	1.24	0.24	0.51	0.26	0.04	727
2014	3.03	0.36	1.24	0.25	0.50	0.25	0.01	1567

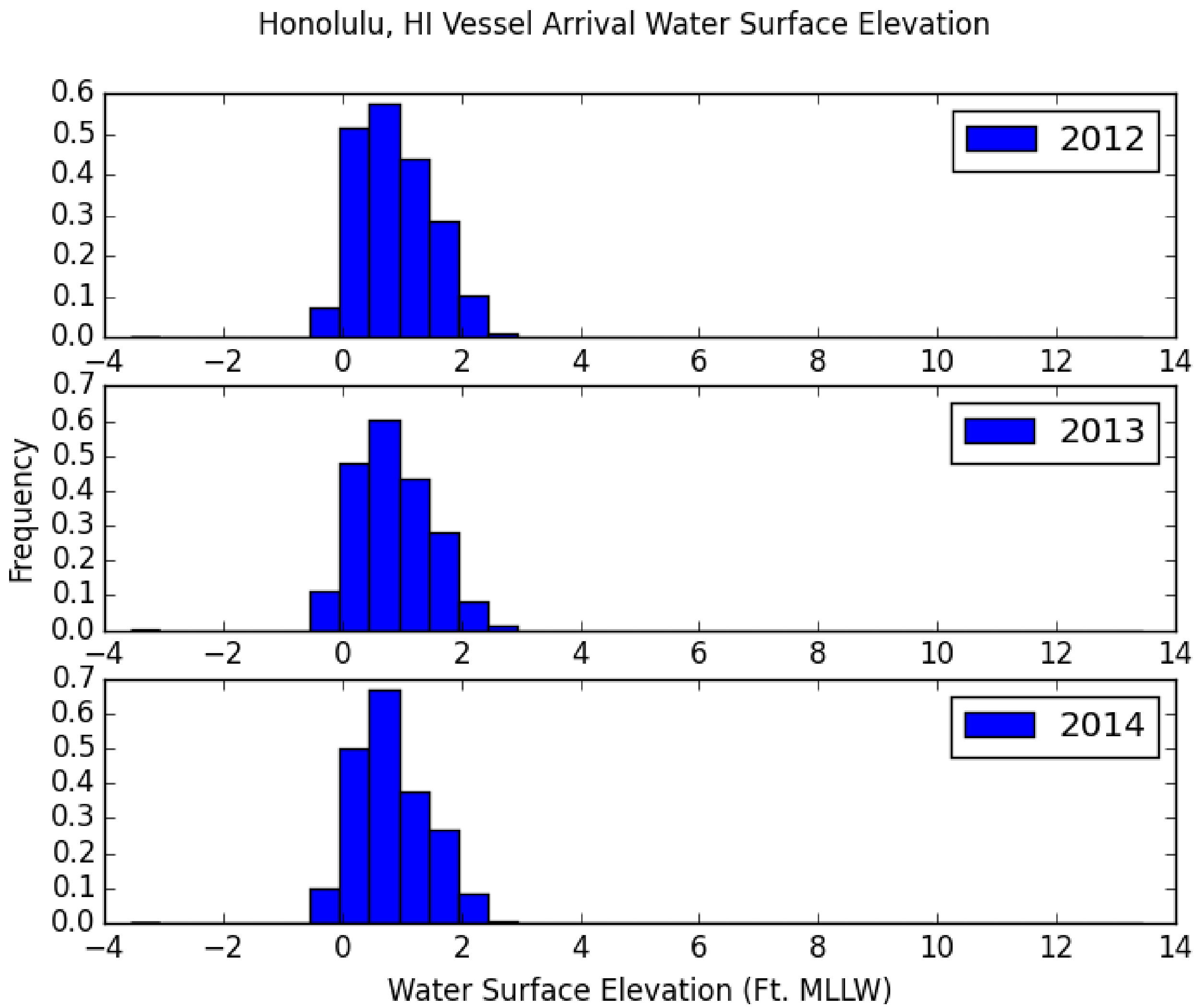



Vessel Call Frequency, Honolulu, HI, 2012
MON 1 3 20 7 8 6 6 32 5 6 5 5 4 5 13 16 16 10 4 2 3 3 1 3
TUE 2 5 8 4 3 11 1 10 5 4 9 6 6 5 8 14 10 2 3 2 4 1 0 3
WED 4 4 10 5 6 5 1 3 2 1 4 2 2 3 1 5 5 5 0 1 1 4 1 5
THU 6 4 11 7 6 32 13 8 7 4 0 2 2 2 1 5 5 5 3 2 3 2 1 1
FRI 1 1 2 0 1 4 0 4 4 4 5 3 4 6 7 5 6 6 2 0 0 3 2 3
SAT 2 5 4 2 5 2 4 4 5 4 2 3 1 2 5 8 1 4 2 2 2 3 3 1
SUN 1 7 13 8 4 3 5 7 3 7 2 0 1 0 1 2 4 1 0 4 2 0 2 0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)


Vessel Call Frequency, Honolulu, HI, 2013
MON 0 20 21 3 7 3 4 29 13 6 4 2 1 1 7 6 15 9 3 1 2 2 0 4
TUE 1 1 6 2 4 8 4 9 6 8 7 4 5 9 12 20 10 11 4 3 2 1 1 3
WED 2 3 8 5 1 3 0 1 3 0 1 0 1 0 3 2 2 2 0 1 3 5 2 6
THU 2 13 6 9 13 40 8 5 2 2 2 1 2 0 2 3 1 7 0 2 2 1 3 1
FRI 1 1 5 1 0 1 3 1 2 3 5 3 4 4 10 6 5 11 6 3 3 0 1 1
SAT 3 4 7 1 5 8 6 5 2 5 5 2 4 3 3 2 0 3 1 2 1 4 8 4
SUN 1 2 8 6 7 5 6 7 2 0 1 2 0 1 1 2 3 3 3 4 2 4 2 2
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)


Vessel Call Frequency, Honolulu, HI, 2014
MON 5 27 19 8 11 7 3 36 7 3 4 5 10 13 9 13 20 21 11 7 10 5 9 7
TUE 13 4 11 7 9 9 14 6 4 7 13 3 5 13 13 11 13 10 5 5 12 10 6 9
WED 6 11 21 5 12 13 6 6 6 7 3 2 5 3 4 14 14 2 11 12 13 7 10 10
THU 3 15 11 16 17 41 17 23 11 6 3 1 3 2 7 15 7 15 14 23 16 20 13 8
FRI 5 3 6 9 10 6 9 4 5 0 3 2 2 8 6 16 13 7 9 13 5 7 13 12
SAT 6 6 11 11 11 12 7 10 11 7 6 4 17 8 4 10 6 7 8 8 12 7 8 9
SUN 5 14 26 15 14 9 8 10 6 4 3 3 5 2 4 8 9 9 7 5 8 6 10 6
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)

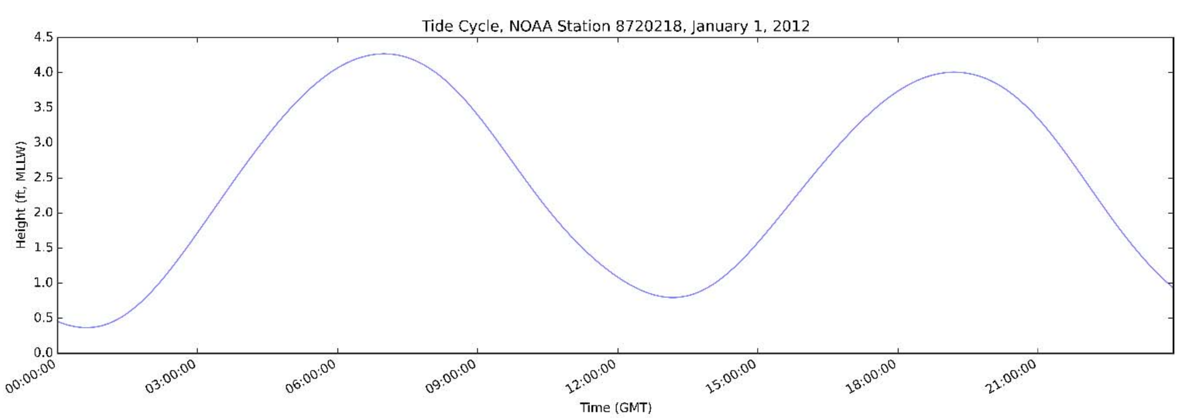

Honolulu, HI Interarrival Times
2012
2013
2014
Frequency
Time Between Arrivals (Hours)
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.10
0.15
0.20
0.25
0
10
20
30
40

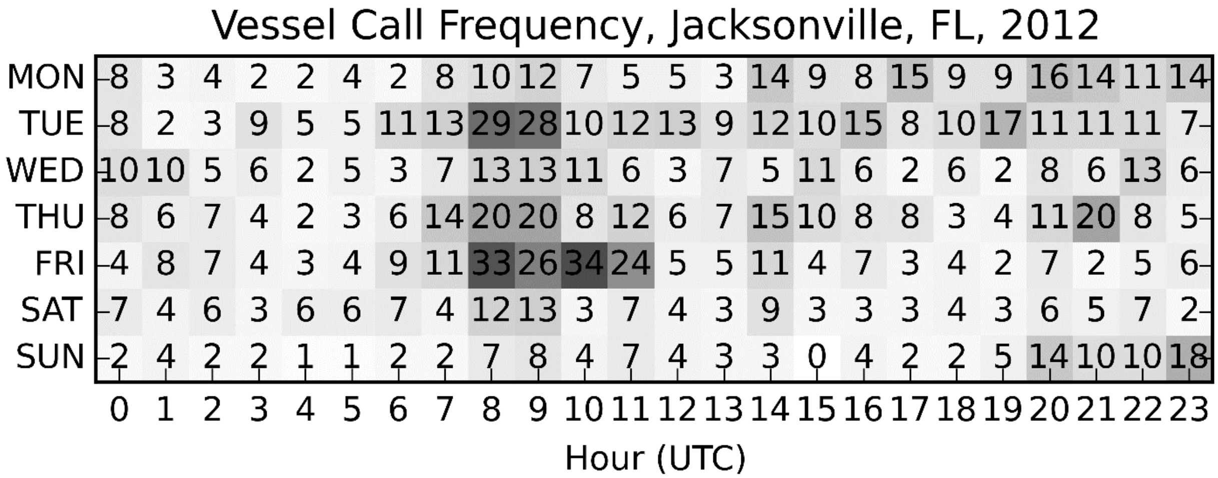

Honolulu, HI Vessel Arrival Water Surface Elevation
2012
2013
2014
Frequency
Water Surface Elevation (Ft. MLLW)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
−4
−2
0
2
4
6
8
10
12
14

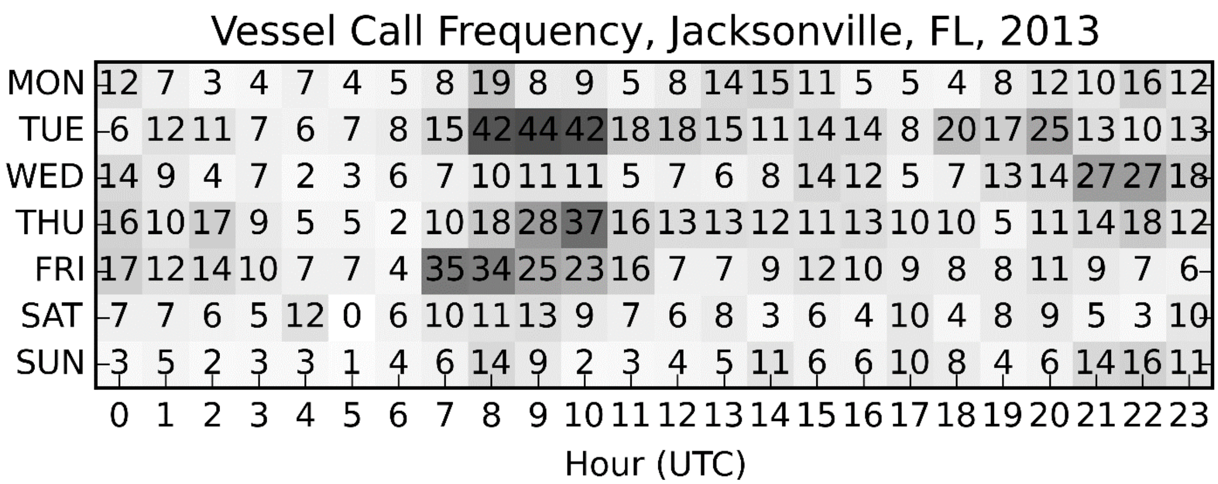
Port of Interest: **Jacksonville, FL**

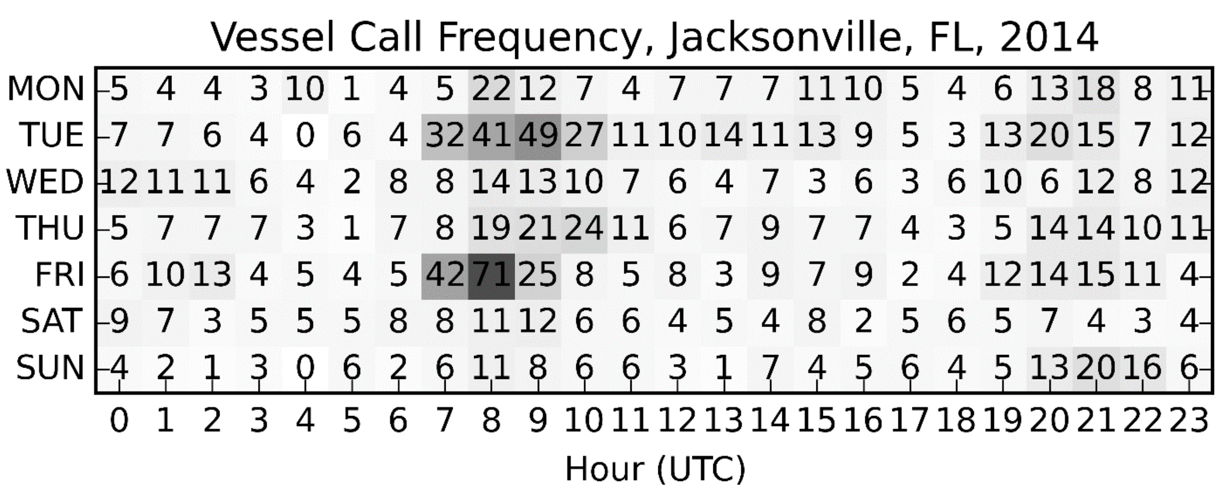
Tide Station Number: 8720218

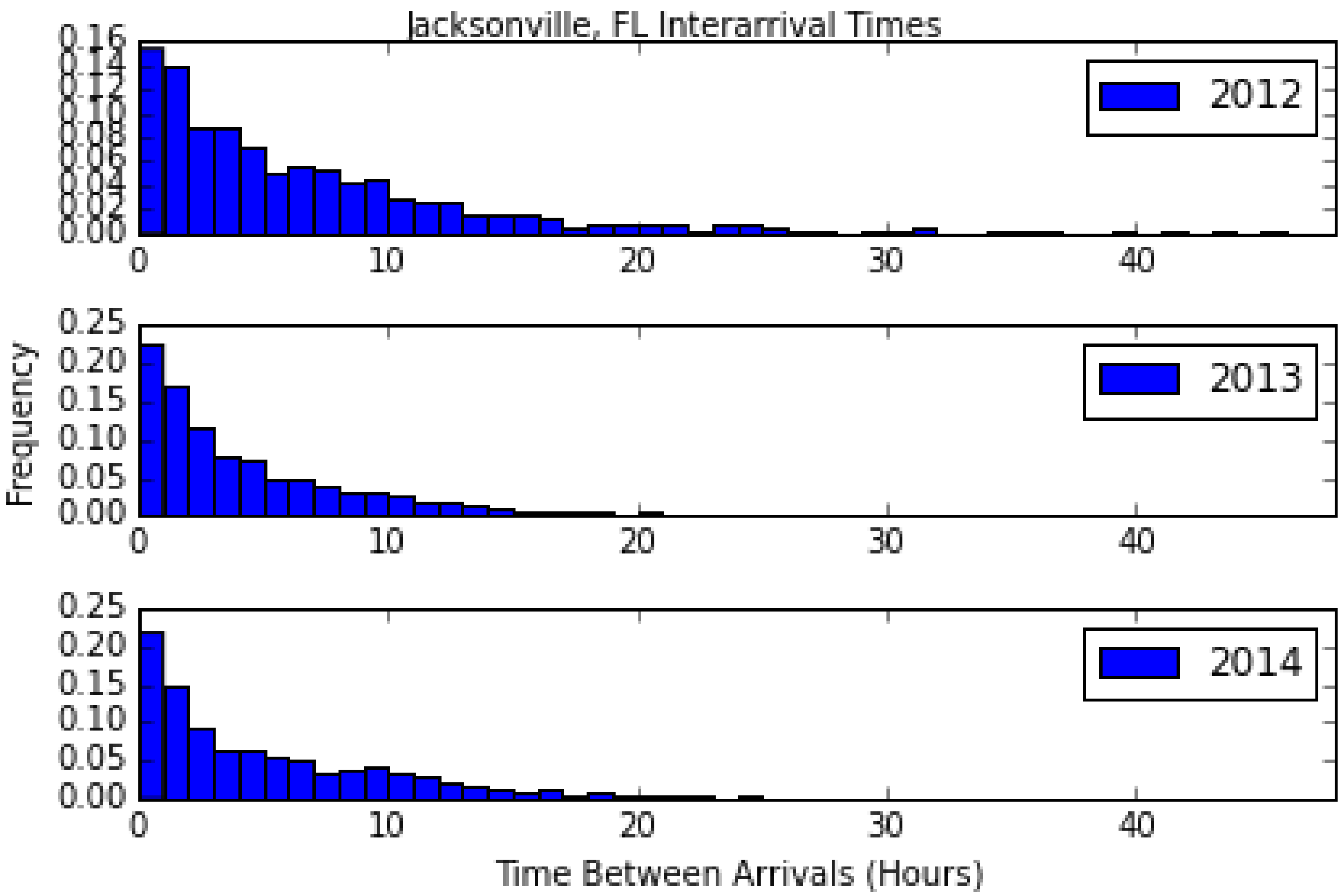
Year	Tide Range (Ft.)	Z_{25} (Ft.)	Z_{75} (Ft.)	T_{25}	T_{50}	T_{75}	TD	Arrivals
2012	7.39	0.94	4.00	0.21	0.53	0.26	0.10	1447
2013	7.36	0.93	4.03	0.22	0.52	0.27	0.10	6524
2014	7.75	0.93	4.04	0.24	0.53	0.24	0.01	5240

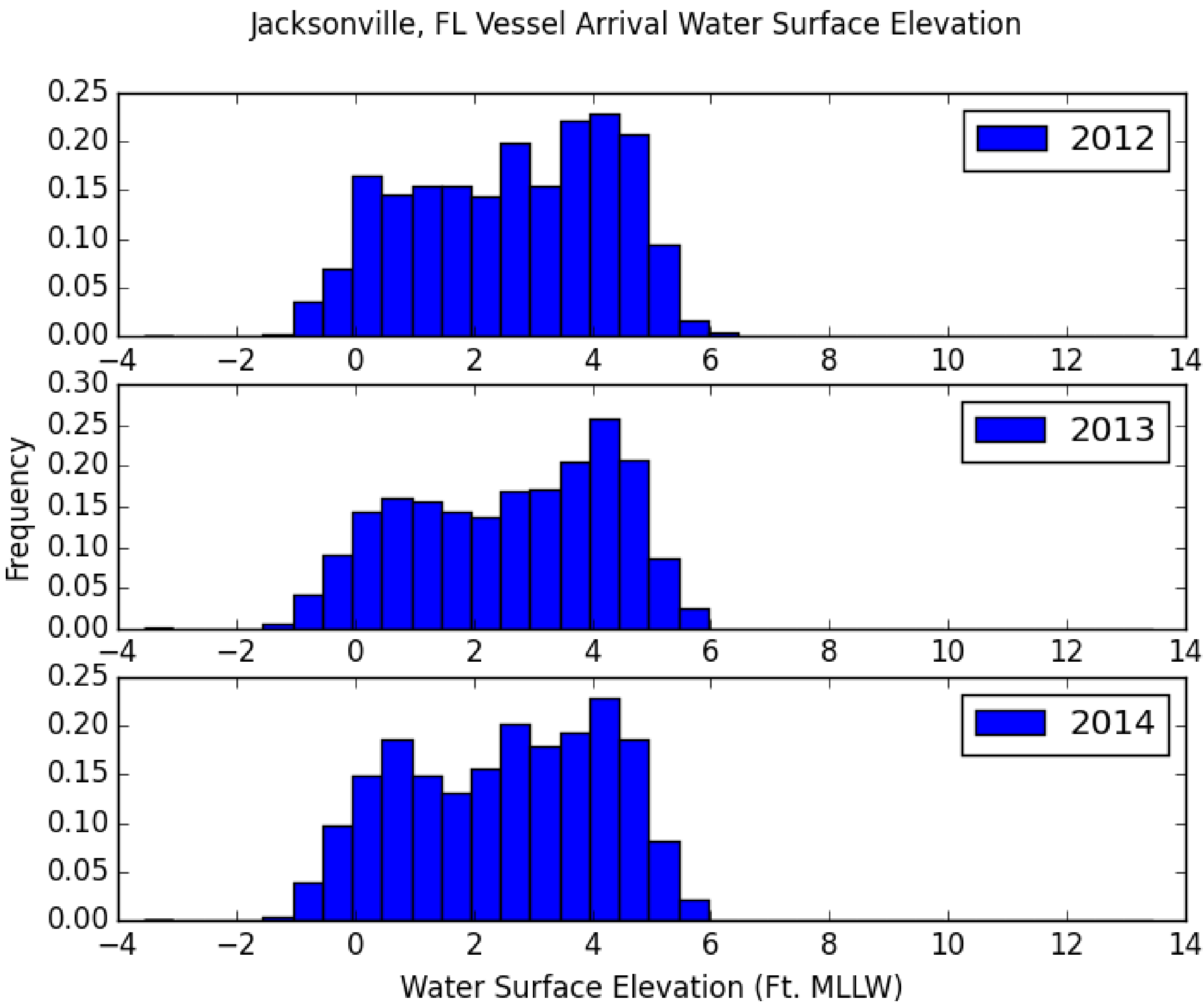



Vessel Call Frequency, Jacksonville, FL, 2012
MON 8 3 4 2 2 4 2 8 10 12 7 5 5 3 14 9 8 15 9 9 16 14 11 14
TUE 8 2 3 9 5 5 11 13 29 28 10 12 13 9 12 10 15 8 10 17 11 11 11 7
WED 10 10 5 6 2 5 3 7 13 13 11 6 3 7 5 11 6 2 6 2 8 6 13 6
THU 8 6 7 4 2 3 6 14 20 20 8 12 6 7 15 10 8 8 3 4 11 20 8 5
FRI 4 8 7 4 3 4 9 11 33 26 34 24 5 5 11 4 7 3 4 2 7 2 5 6
SAT 7 4 6 3 6 6 7 4 12 13 3 7 4 3 9 3 3 3 4 3 6 5 7 2
SUN 2 4 2 2 1 1 2 2 7 8 4 7 4 3 3 0 4 2 2 5 14 10 10 18
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)

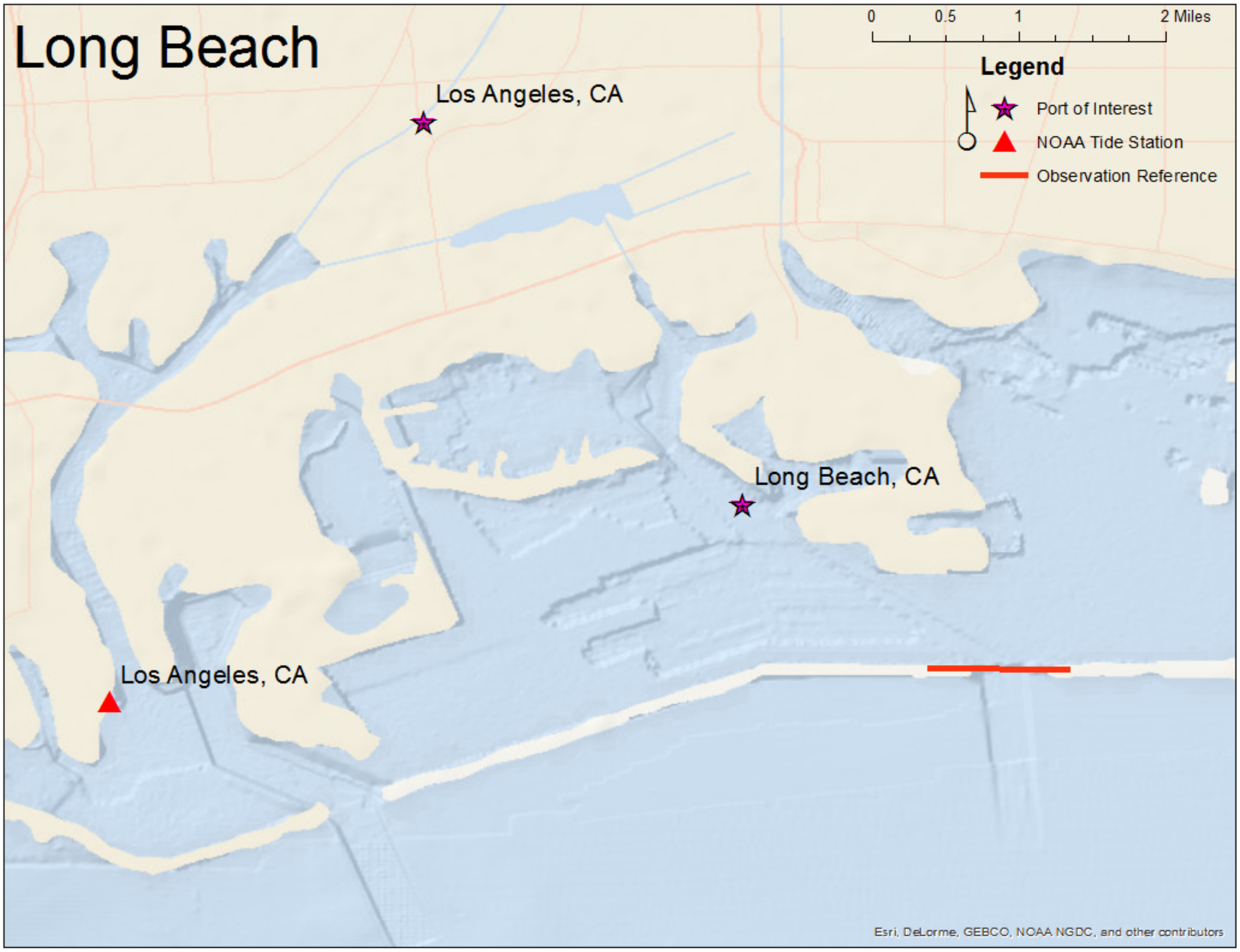

Vessel Call Frequency, Jacksonville, FL, 2013
MON 12 7 3 4 7 4 5 8 19 8 9 5 8 14 15 11 5 5 4 8 12 10 16 12
TUE 6 12 11 7 6 7 8 15 42 44 42 18 18 15 11 14 14 8 20 17 25 13 10 13
WED 14 9 4 7 2 3 6 7 10 11 11 5 7 6 8 14 12 5 7 13 14 27 27 18
THU 16 10 17 9 5 5 2 10 18 28 37 16 13 13 12 11 13 10 10 5 11 14 18 12
FRI 17 12 14 10 7 7 4 35 34 25 23 16 7 7 9 12 10 9 8 8 11 9 7 6
SAT 7 7 6 5 12 0 6 10 11 13 9 7 6 8 3 6 4 10 4 8 9 5 3 10
SUN 3 5 2 3 3 1 4 6 14 9 2 3 4 5 11 6 6 10 8 4 6 14 16 11
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)


Vessel Call Frequency, Jacksonville, FL, 2014
MON 5 4 4 3 10 1 4 5 22 12 7 4 7 7 7 11 10 5 4 6 13 18 8 11
TUE 7 7 6 4 0 6 4 32 41 49 27 11 10 14 11 13 9 5 3 13 20 15 7 12
WED 12 11 11 6 4 2 8 8 14 13 10 7 6 4 7 3 6 3 6 10 6 12 8 12
THU 5 7 7 7 3 1 7 8 19 21 24 11 6 7 9 7 7 4 3 5 14 14 10 11
FRI 6 10 13 4 5 4 5 42 71 25 8 5 8 3 9 7 9 2 4 12 14 15 11 4
SAT 9 7 3 5 5 5 8 8 11 12 6 6 4 5 4 8 2 5 6 5 7 4 3 4
SUN 4 2 1 3 0 6 2 6 11 8 6 6 3 1 7 4 5 6 4 5 13 20 16 6
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)


Jacksonville, FL Interarrival Times
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
2012
0
10
20
30
40
0.25
0.20
0.15
0.10
0.05
0.00
2013
Frequency
2014
Time Between Arrivals (Hours)



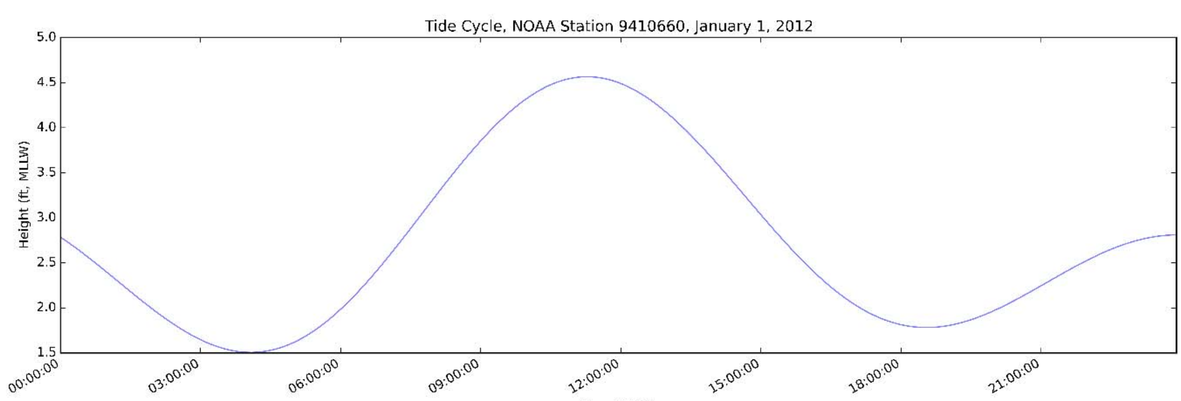
Jacksonville, FL Vessel Arrival Water Surface Elevation
Frequency
2012
2013
2014
0.00
0.05
0.10
0.15
0.20
0.25
0.30
−4
−2
0
2
4
6
8
10
12
14
Water Surface Elevation (Ft. MLLW)

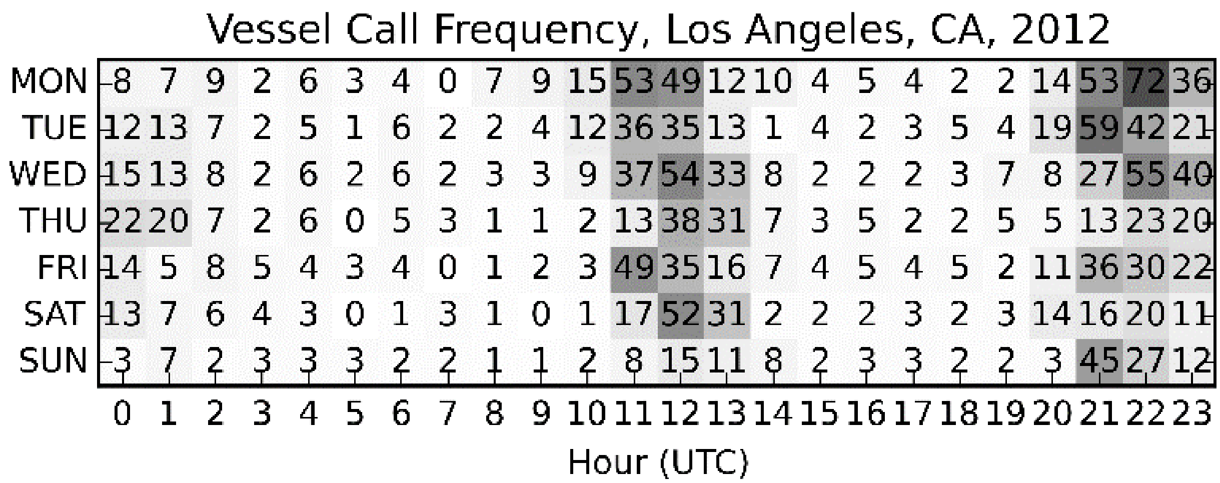


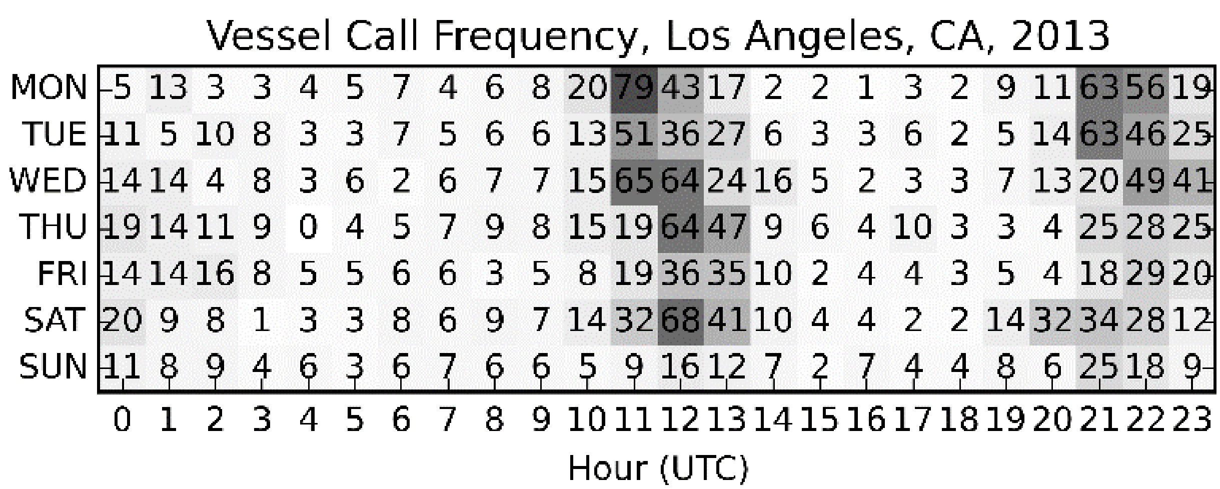
Port of Interest: **Long Beach, CA**

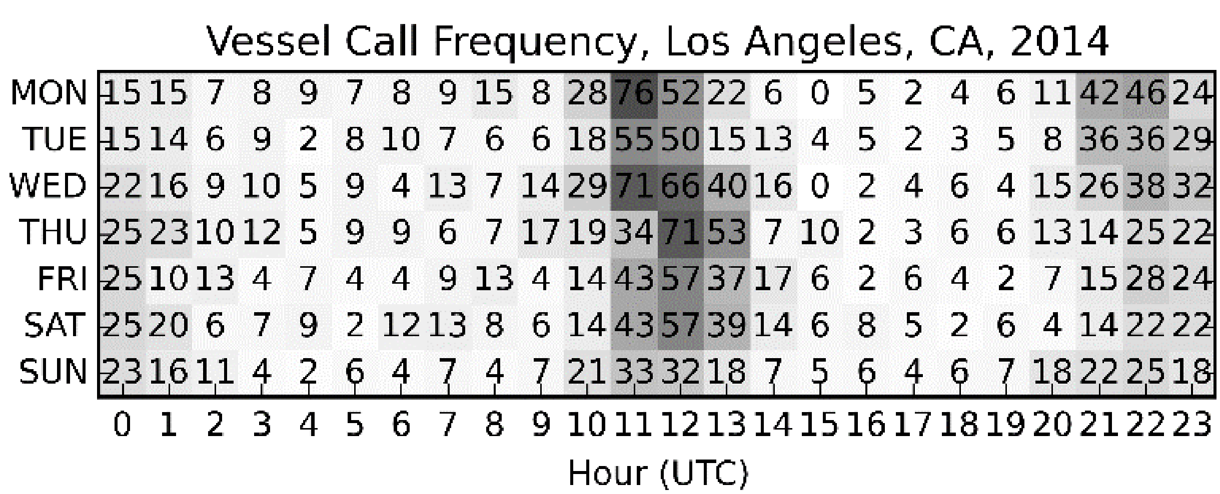
Tide Station Number: 9410660

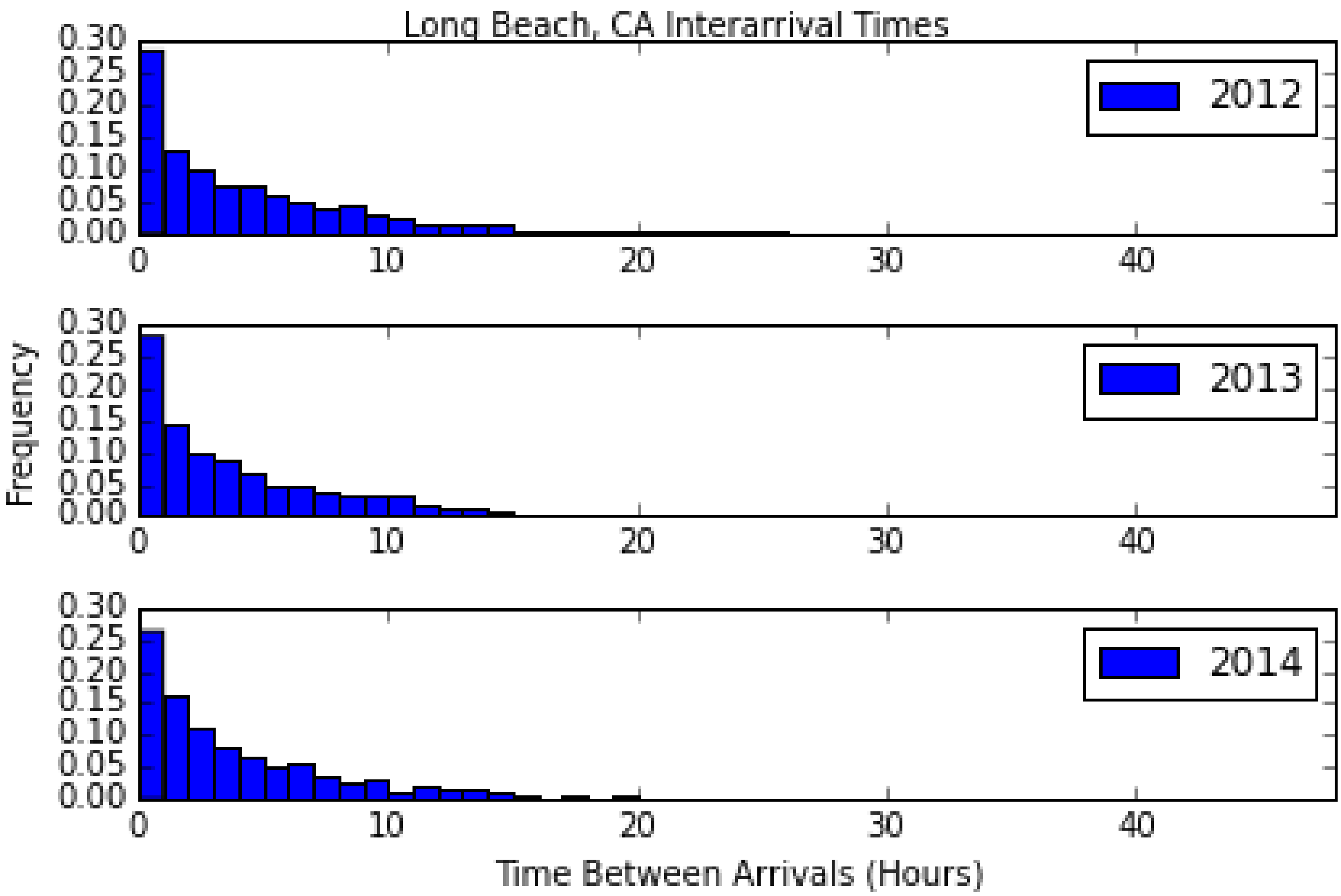
Year	Tide Range (Ft.)	Z_{25} (Ft.)	Z_{75} (Ft.)	T_{25}	T_{50}	T_{75}	TD	Arrivals
2012	9.03	1.70	4.00	0.27	0.51	0.21	-0.11	1957
2013	8.82	1.68	3.99	0.30	0.49	0.20	-0.20	2019
2014	8.78	1.68	3.99	0.31	0.49	0.21	-0.20	2033



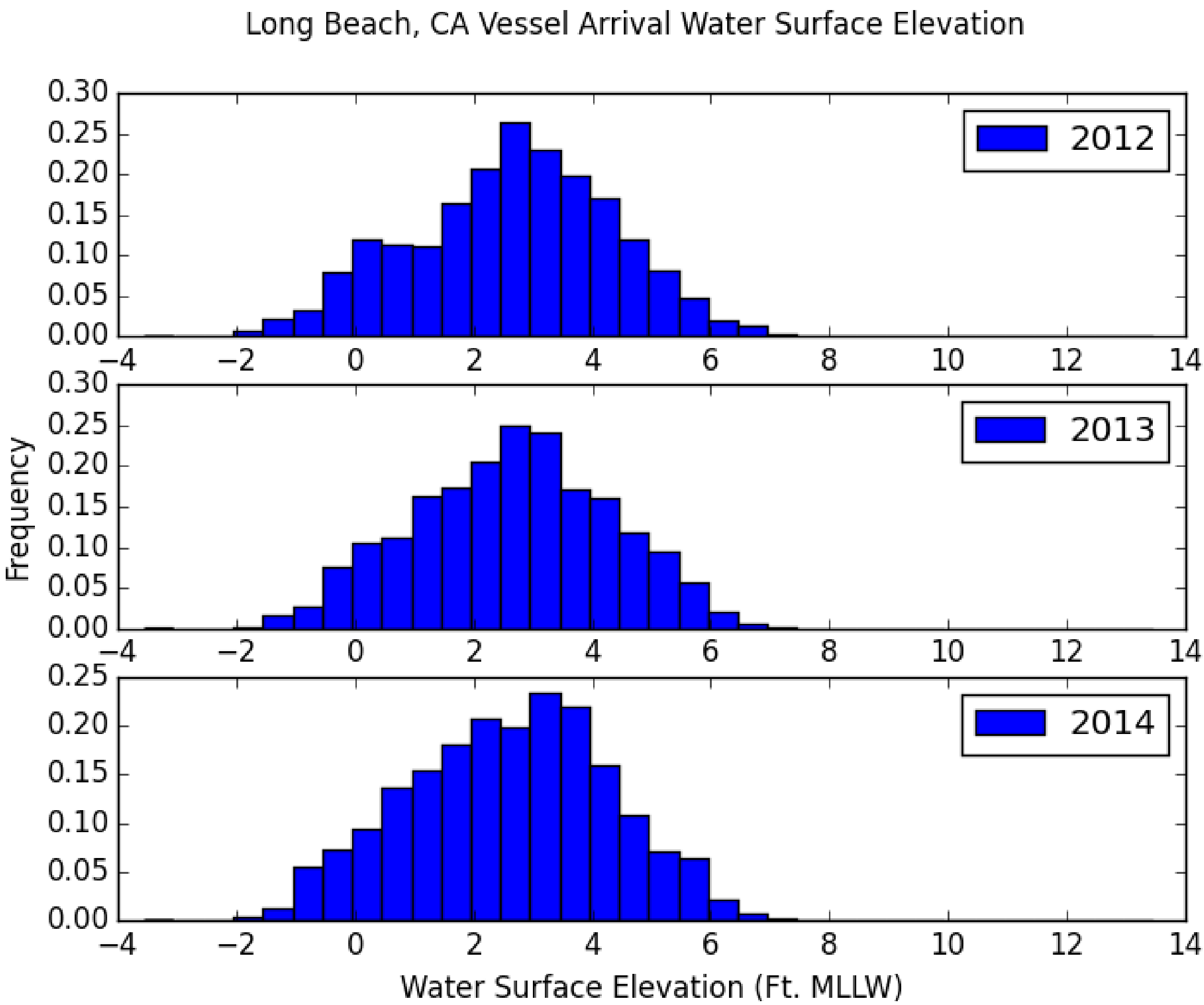

Vessel Call Frequency, Los Angeles, CA, 2012
MON 8 7 9 2 6 3 4 0 7 9 15 53 49 12 10 4 5 4 2 2 14 53 72 36
TUE 12 13 7 2 5 1 6 2 2 4 12 36 35 13 1 4 2 3 5 4 19 59 42 21
WED 15 13 8 2 6 2 6 2 3 3 9 37 54 33 8 2 2 2 3 7 8 27 55 40
THU 22 20 7 2 6 0 5 3 1 1 2 13 38 31 7 3 5 2 2 5 5 13 23 20
FRI 14 5 8 5 4 3 4 0 1 2 3 49 35 16 7 4 5 4 5 2 11 36 30 22
SAT 13 7 6 4 3 0 1 3 1 0 1 17 52 31 2 2 2 3 2 3 14 16 20 11
SUN 3 7 2 3 3 3 2 2 1 1 2 8 15 11 8 2 3 3 2 2 3 45 27 12
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)

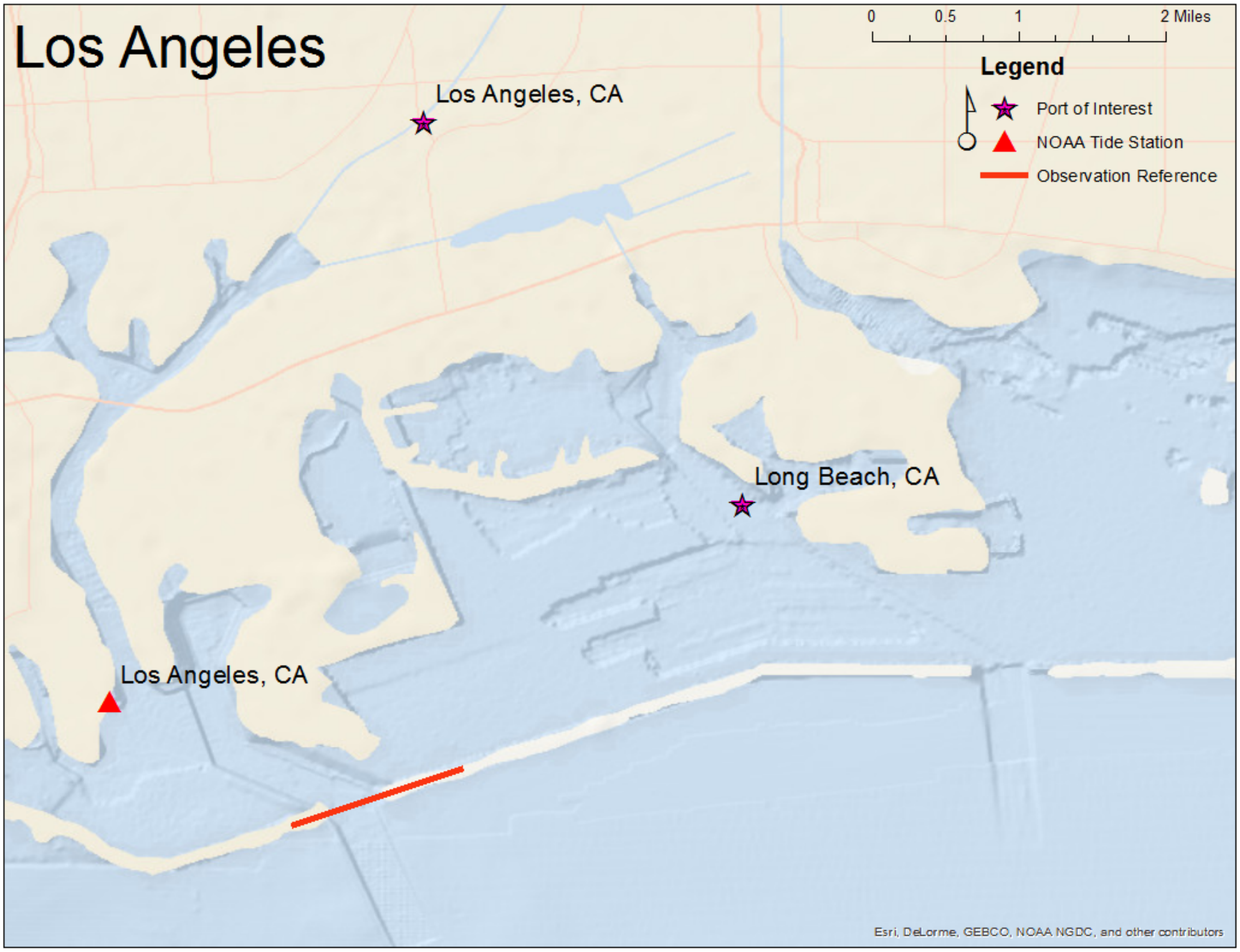

Vessel Call Frequency, Los Angeles, CA, 2013
MON 5 13 3 3 4 5 7 4 6 8 20 79 43 17 2 2 1 3 2 9 11 63 56 19
TUE 11 5 10 8 3 3 7 5 6 6 13 51 36 27 6 3 3 6 2 5 14 63 46 25
WED 14 14 4 8 3 6 2 6 7 7 15 65 64 24 16 5 2 3 3 7 13 20 49 41
THU 19 14 11 9 0 4 5 7 9 8 15 19 64 47 9 6 4 10 3 3 4 25 28 25
FRI 14 14 16 8 5 5 6 6 3 5 8 19 36 35 10 2 4 4 3 5 4 18 29 20
SAT 20 9 8 1 3 3 8 6 9 7 14 32 68 41 10 4 4 2 2 14 32 34 28 12
SUN 11 8 9 4 6 3 6 7 6 6 5 9 16 12 7 2 7 4 4 8 6 25 18 9
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)


Vessel Call Frequency, Los Angeles, CA, 2014
MON 15 15 7 8 9 7 8 9 15 8 28 76 52 22 6 0 5 2 4 6 11 42 46 24
TUE 15 14 6 9 2 8 10 7 6 6 18 55 50 15 13 4 5 2 3 5 8 36 36 29
WED 22 16 9 10 5 9 4 13 7 14 29 71 66 40 16 0 2 4 6 4 15 26 38 32
THU 25 23 10 12 5 9 9 6 7 17 19 34 71 53 7 10 2 3 6 6 13 14 25 22
FRI 25 10 13 4 7 4 4 9 13 4 14 43 57 37 17 6 2 6 4 2 7 15 28 24
SAT 25 20 6 7 9 2 12 13 8 6 14 43 57 39 14 6 8 5 2 6 4 14 22 22
SUN 23 16 11 4 2 6 4 7 4 7 21 33 32 18 7 5 6 4 6 7 18 22 25 18
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)



Long Beach, CA Interarrival Times
2012
2013
2014
Frequency
Time Between Arrivals (Hours)
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
10
20
30
40

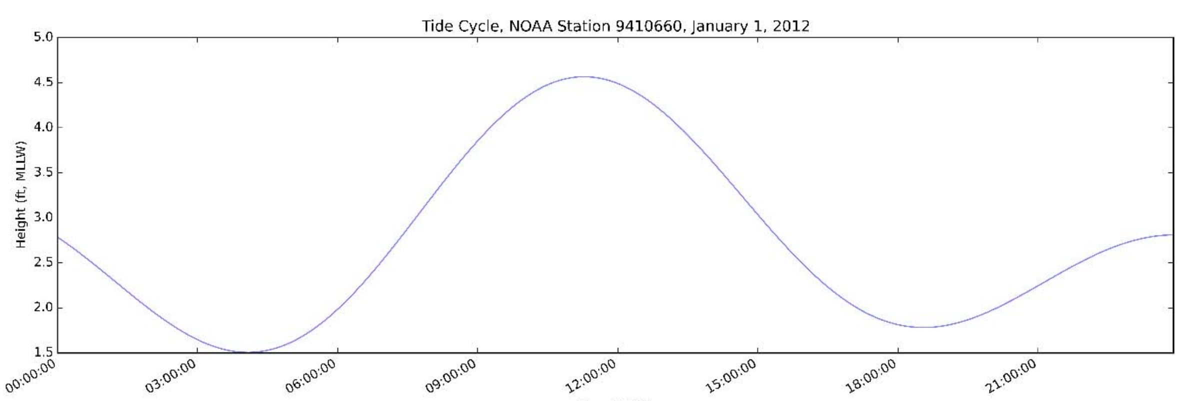

Long Beach, CA Vessel Arrival Water Surface Elevation
2012
2013
2014
Frequency
Water Surface Elevation (Ft. MLLW)
0.30
0.25
0.20
0.15
0.10
0.05
0.00
−4
−2
0
2
4
6
8
10
12
14

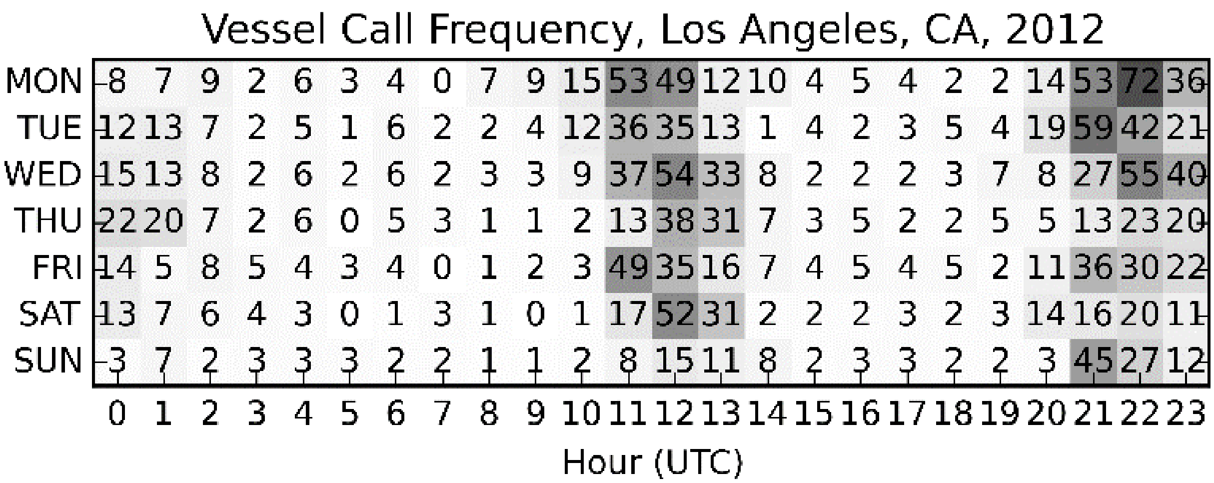


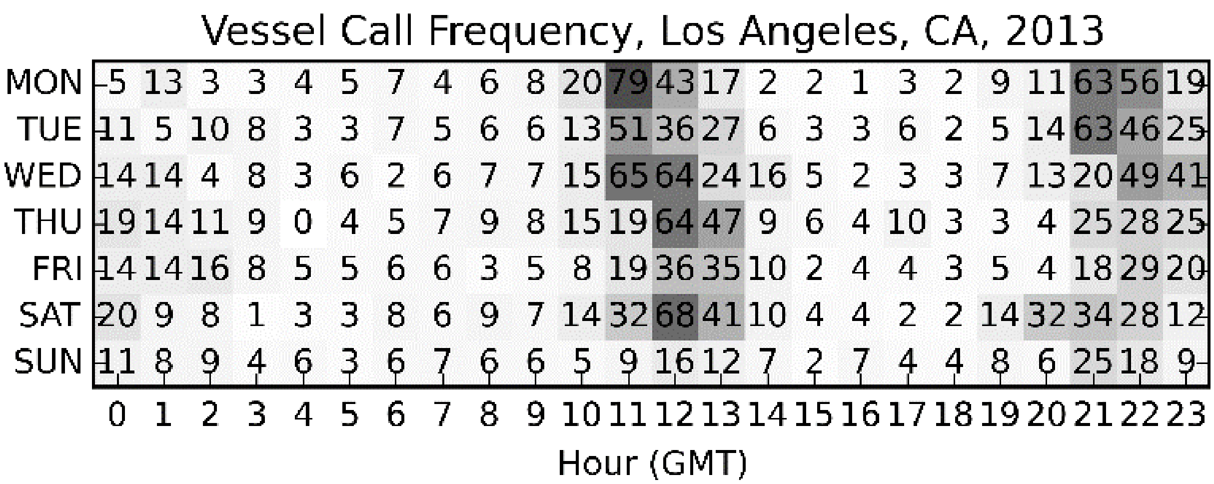
Port of Interest: **Los Angeles, CA**

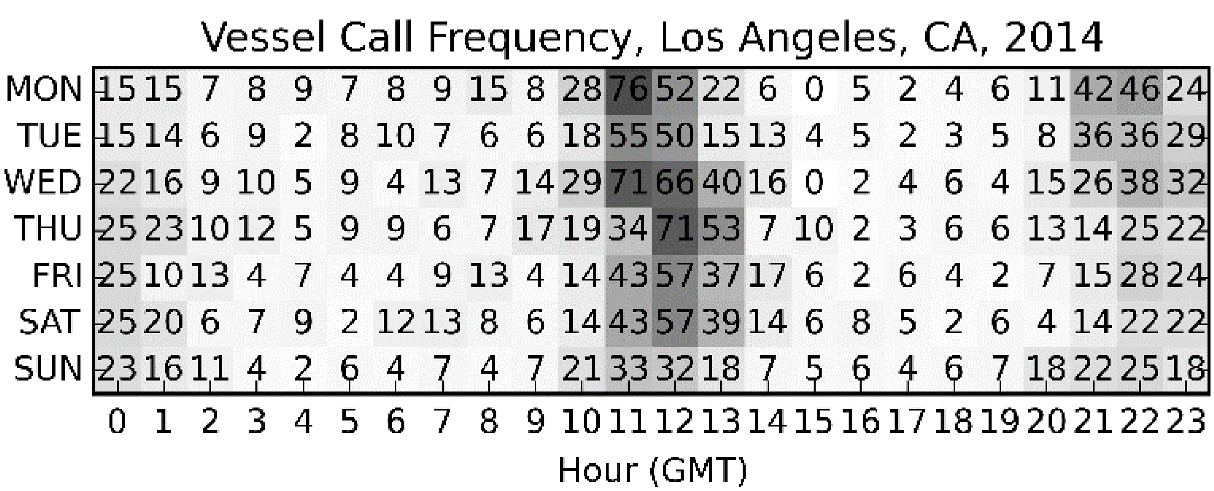
Tide Station Number: 9410660

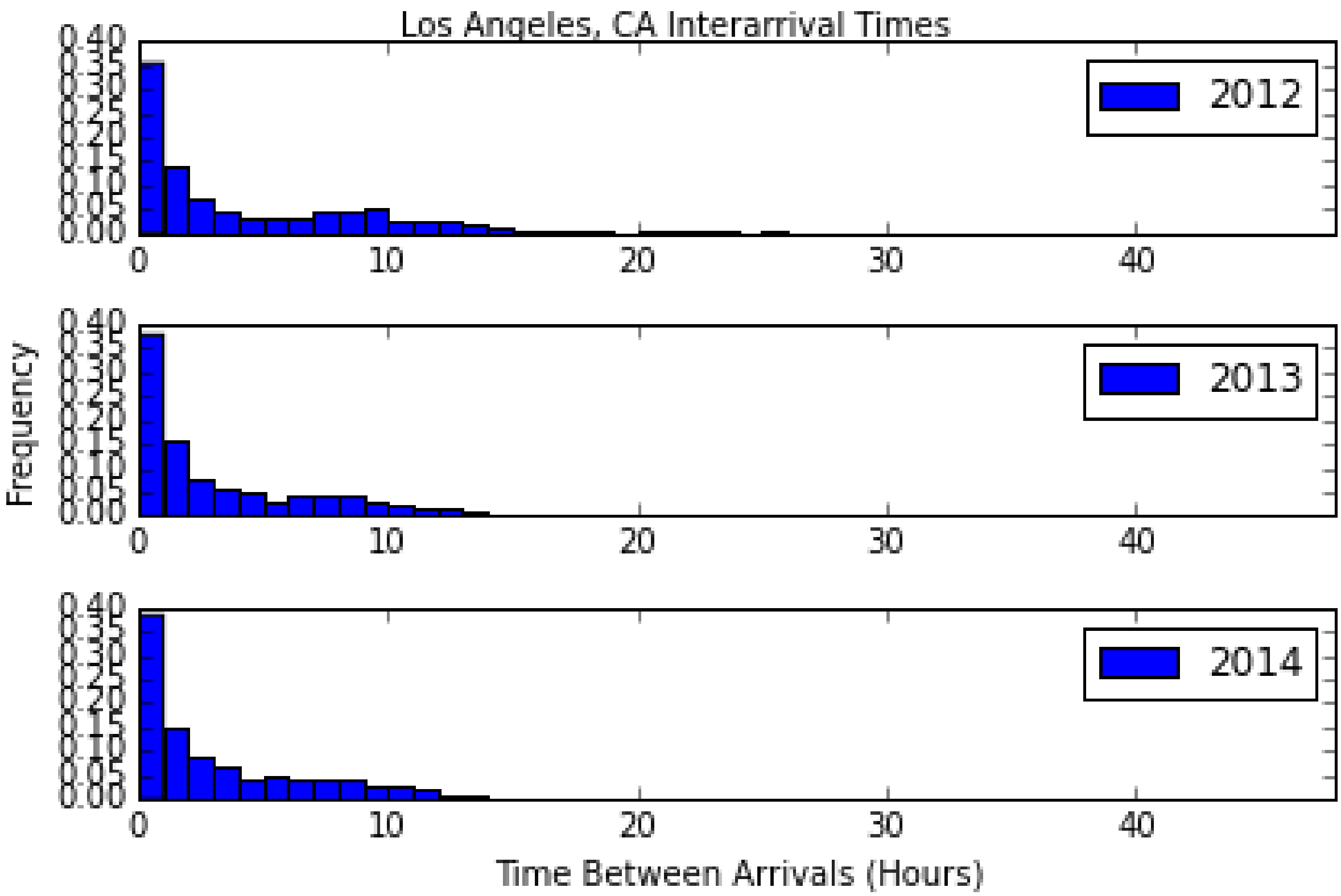
Year	Tide Range (Ft.)	Z_{25} (Ft.)	Z_{75} (Ft.)	T_{25}	T_{50}	T_{75}	TD	Arrivals
2012	9.03	1.70	4.00	0.28	0.51	0.20	-0.16	1938
2013	8.82	1.68	3.99	0.29	0.51	0.20	-0.18	2343
2014	8.78	1.68	3.99	0.30	0.50	0.20	-0.19	2678

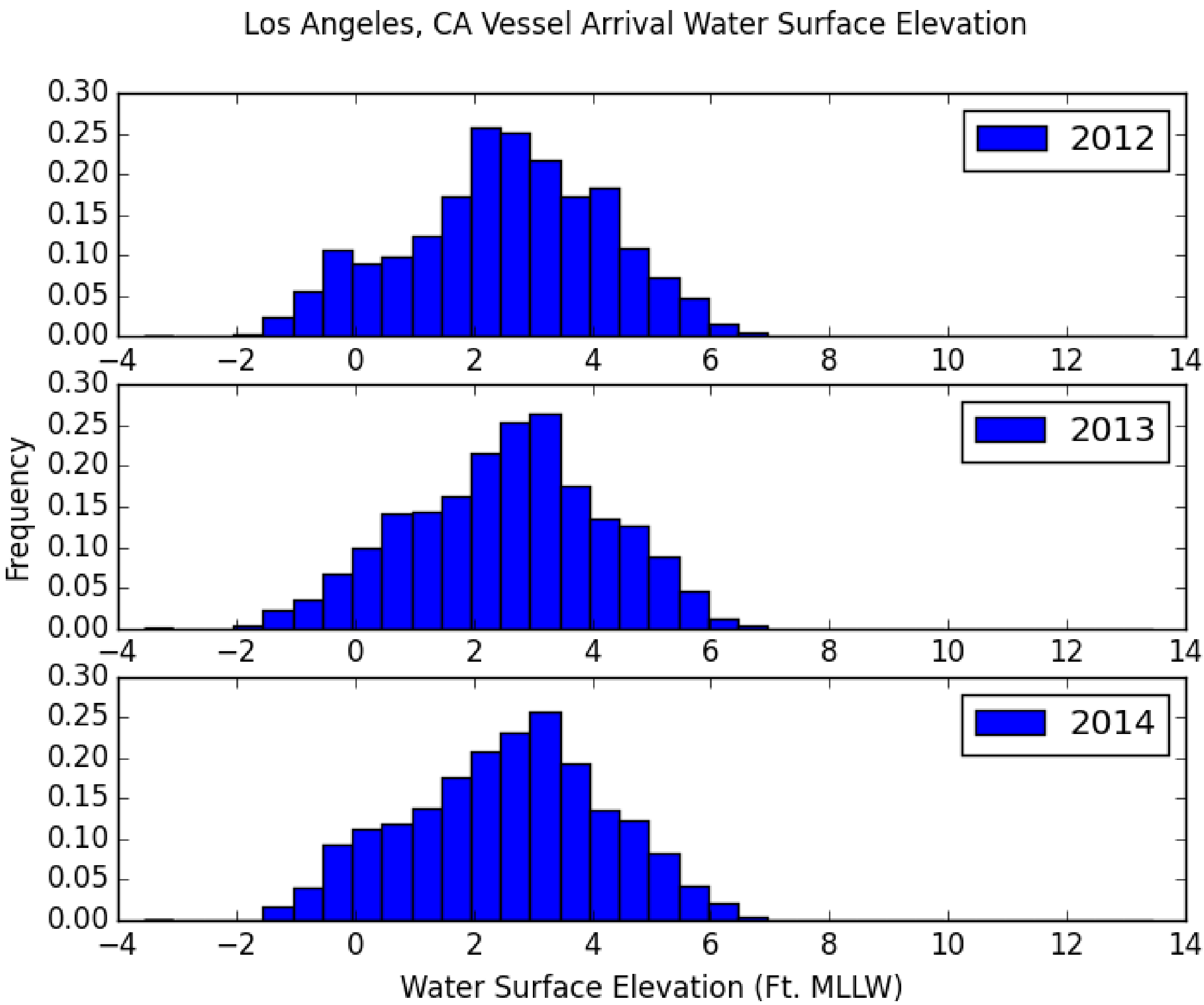


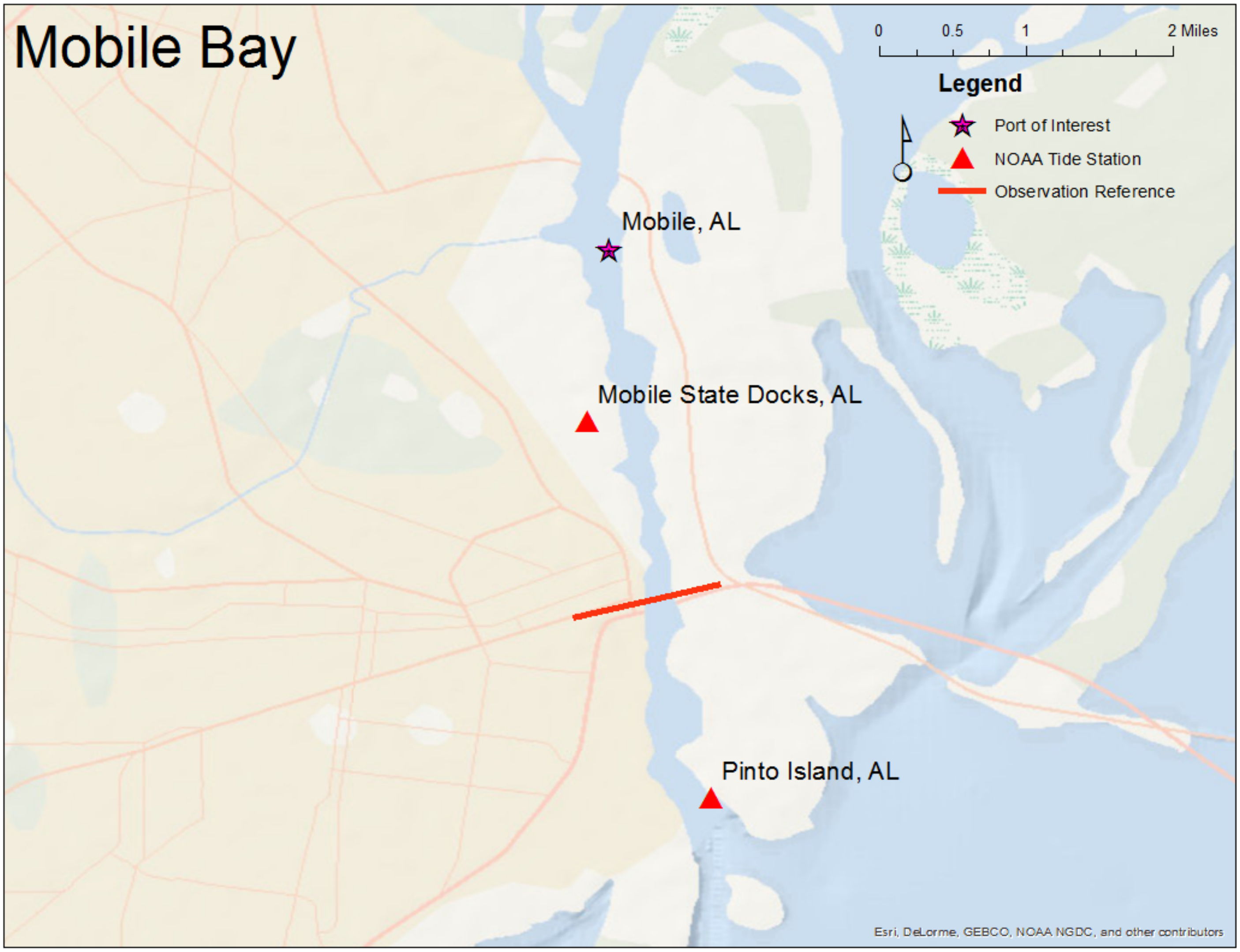

Vessel Call Frequency, Los Angeles, CA, 2012
MON 8 7 9 2 6 3 4 0 7 9 15 53 49 12 10 4 5 4 2 2 14 53 72 36
TUE 12 13 7 2 5 1 6 2 2 4 12 36 35 13 1 4 2 3 5 4 19 59 42 21
WED 15 13 8 2 6 2 6 2 3 3 9 37 54 33 8 2 2 2 3 7 8 27 55 40
THU 22 20 7 2 6 0 5 3 1 1 2 13 38 31 7 3 5 2 2 5 5 13 23 20
FRI 14 5 8 5 4 3 4 0 1 2 3 49 35 16 7 4 5 4 5 2 11 36 30 22
SAT 13 7 6 4 3 0 1 3 1 0 1 17 52 31 2 2 2 3 2 3 14 16 20 11
SUN 3 7 2 3 3 3 2 2 1 1 2 8 15 11 8 2 3 3 2 2 3 45 27 12
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)


Vessel Call Frequency, Los Angeles, CA, 2013
MON 5 13 3 3 4 5 7 4 6 8 20 79 43 17 2 2 1 3 2 9 11 63 56 19
TUE 11 5 10 8 3 3 7 5 6 6 13 51 36 27 6 3 3 6 2 5 14 63 46 25
WED 14 14 4 8 3 6 2 6 7 7 15 65 64 24 16 5 2 3 3 7 13 20 49 41
THU 19 14 11 9 0 4 5 7 9 8 15 19 64 47 9 6 4 10 3 3 4 25 28 25
FRI 14 14 16 8 5 5 6 6 3 5 8 19 36 35 10 2 4 4 3 5 4 18 29 20
SAT 20 9 8 1 3 3 8 6 9 7 14 32 68 41 10 4 4 2 2 14 32 34 28 12
SUN 11 8 9 4 6 3 6 7 6 6 5 9 16 12 7 2 7 4 4 8 6 25 18 9
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (GMT)


Vessel Call Frequency, Los Angeles, CA, 2014
MON 15 15 7 8 9 7 8 9 15 8 28 76 52 22 6 0 5 2 4 6 11 42 46 24
TUE 15 14 6 9 2 8 10 7 6 6 18 55 50 15 13 4 5 2 3 5 8 36 36 29
WED 22 16 9 10 5 9 4 13 7 14 29 71 66 40 16 0 2 4 6 4 15 26 38 32
THU 25 23 10 12 5 9 9 6 7 17 19 34 71 53 7 10 2 3 6 6 13 14 25 22
FRI 25 10 13 4 7 4 4 9 13 4 14 43 57 37 17 6 2 6 4 2 7 15 28 24
SAT 25 20 6 7 9 2 12 13 8 6 14 43 57 39 14 6 8 5 2 6 4 14 22 22
SUN 23 16 11 4 2 6 4 7 4 7 21 33 32 18 7 5 6 4 6 7 18 22 25 18
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (GMT)


Los Angeles, CA Interarrival Times
Frequency
Time Between Arrivals (Hours)
2012
2013
2014
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0
10
20
30
40

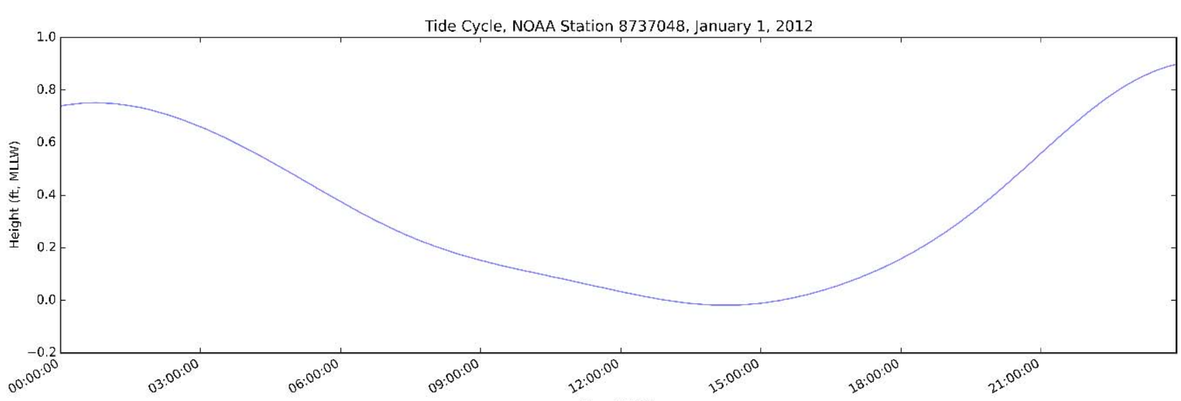

Los Angeles, CA Vessel Arrival Water Surface Elevation
2012
2013
2014
Frequency
Water Surface Elevation (Ft. MLLW)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
−4
−2
0
2
4
6
8
10
12
14

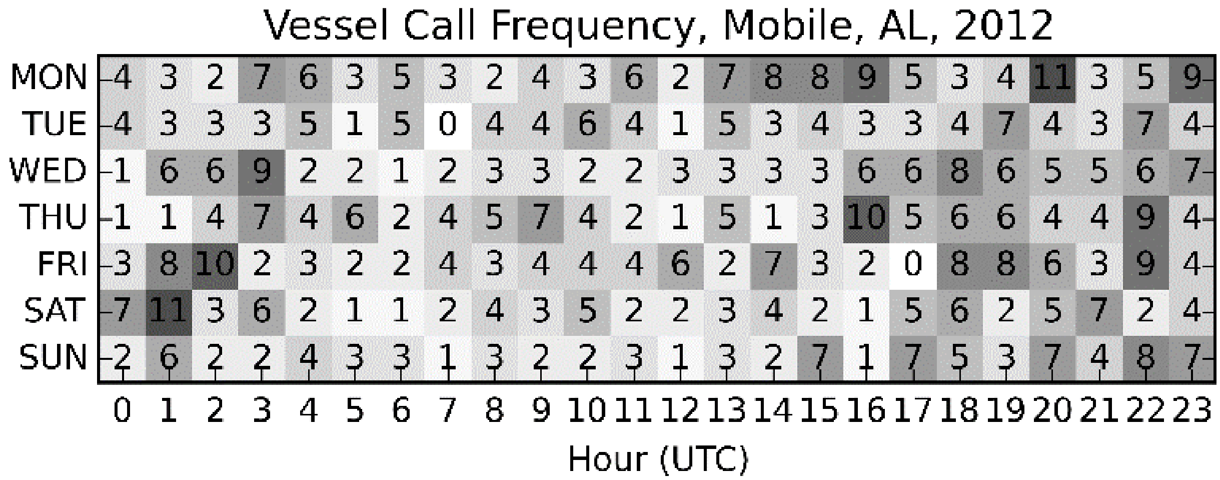


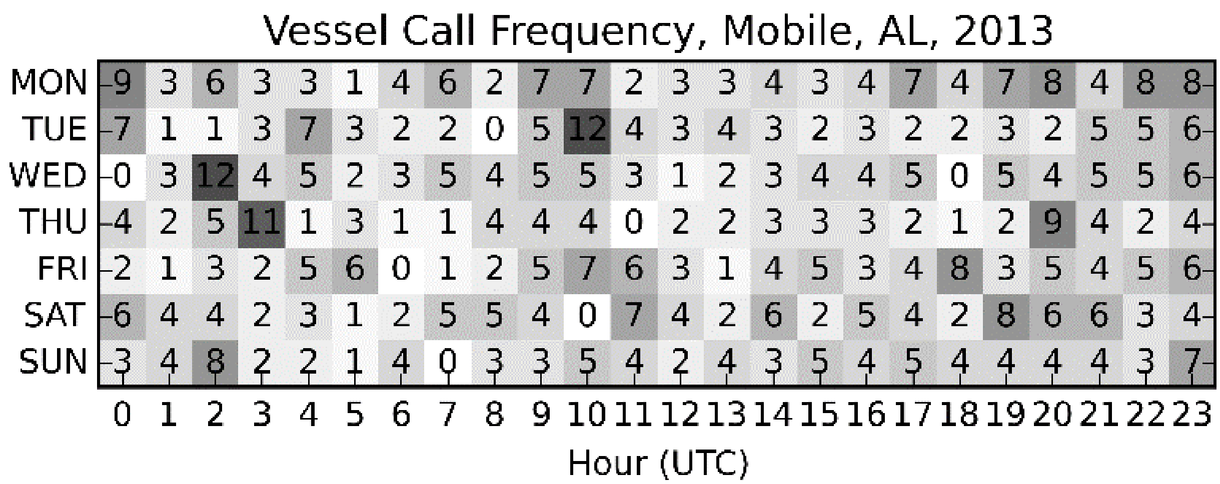
Port of Interest: **Mobile, AL**

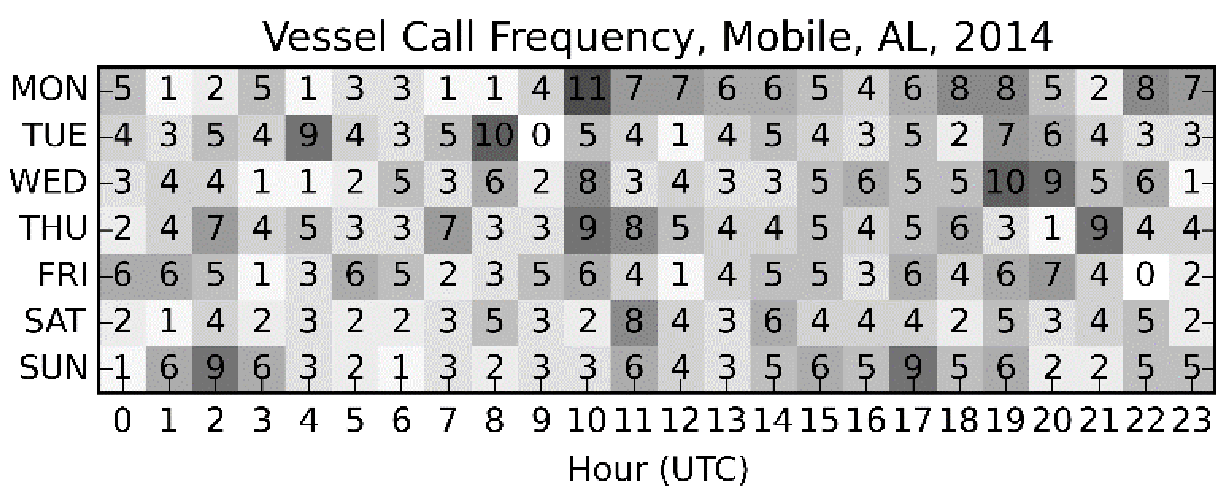
Tide Station Number: 9439040

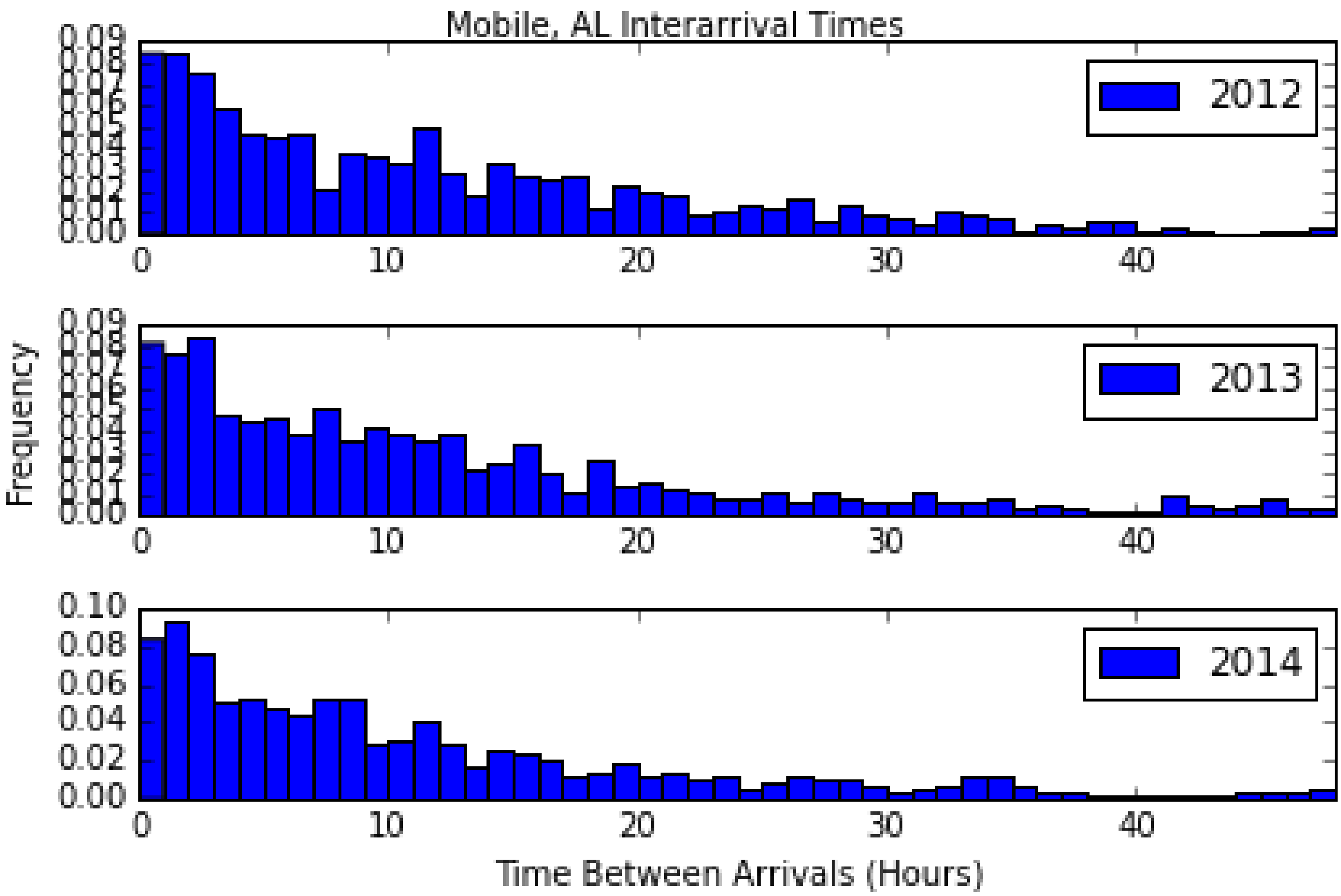
Year	Tide Range (Ft.)	Z_{25} (Ft.)	Z_{75} (Ft.)	T_{25}	T_{50}	T_{75}	TD	Arrivals
2012	2.99	0.42	1.22	0.23	0.50	0.27	0.08	702
2013	3.02	0.44	1.20	0.23	0.53	0.24	0.02	649
2014	2.93	0.45	1.19	0.24	0.48	0.28	0.09	719

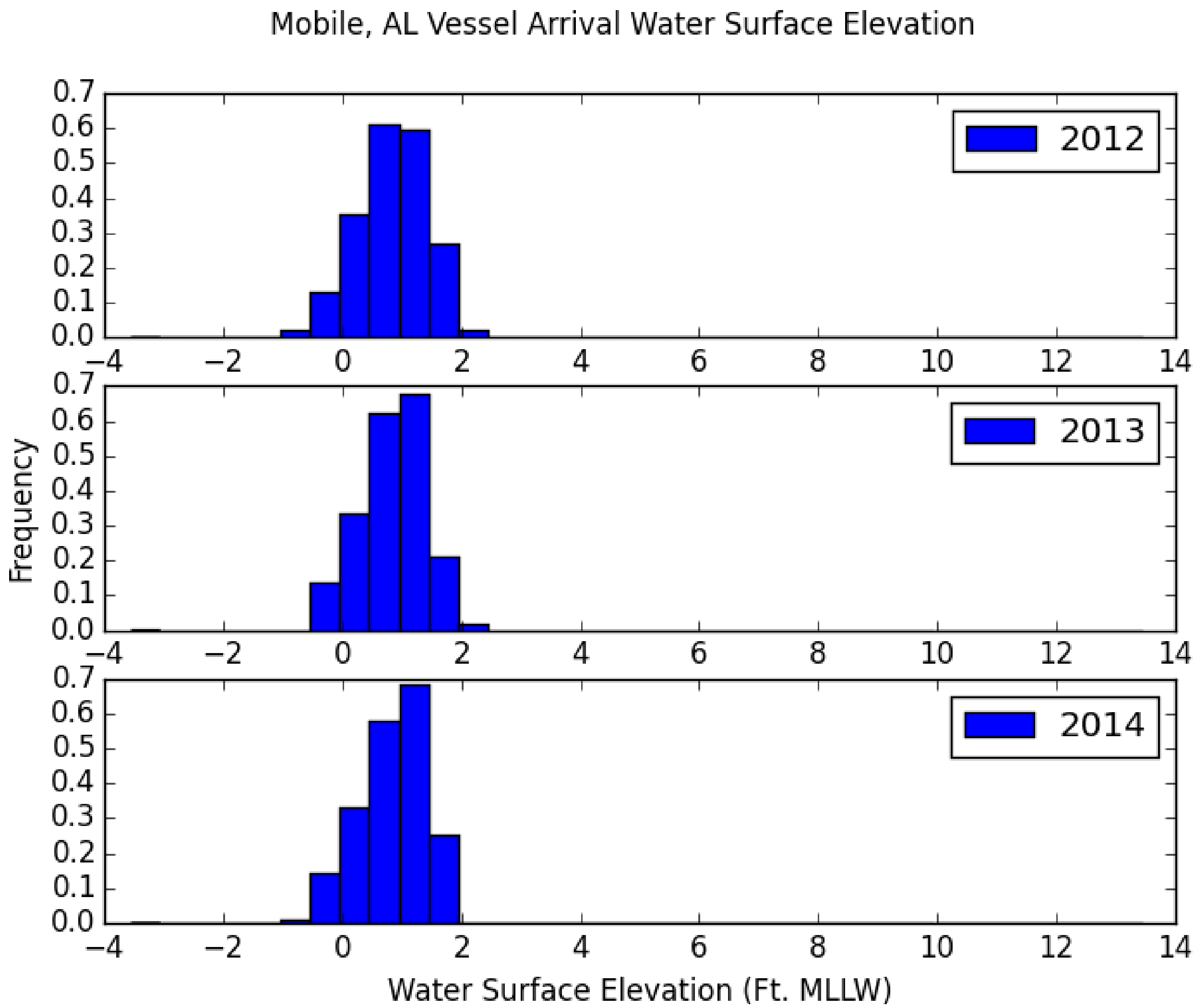



Vessel Call Frequency, Mobile, AL, 2012
MON 4 3 2 7 6 3 5 3 2 4 3 6 2 7 8 8 9 5 3 4 11 3 5 9
TUE 4 3 3 3 5 1 5 0 4 4 6 4 1 5 3 4 3 3 4 7 4 3 7 4
WED 1 6 6 9 2 2 1 2 3 3 2 2 3 3 3 3 6 6 8 6 5 5 6 7
THU 1 1 4 7 4 6 2 4 5 7 4 2 1 5 1 3 10 5 6 6 4 4 9 4
FRI 3 8 10 2 3 2 2 4 3 4 4 4 6 2 7 3 2 0 8 8 6 3 9 4
SAT 7 11 3 6 2 1 1 2 4 3 5 2 2 3 4 2 1 5 6 2 5 7 2 4
SUN 2 6 2 2 4 3 3 1 3 2 2 3 1 3 2 7 1 7 5 3 7 4 8 7
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)

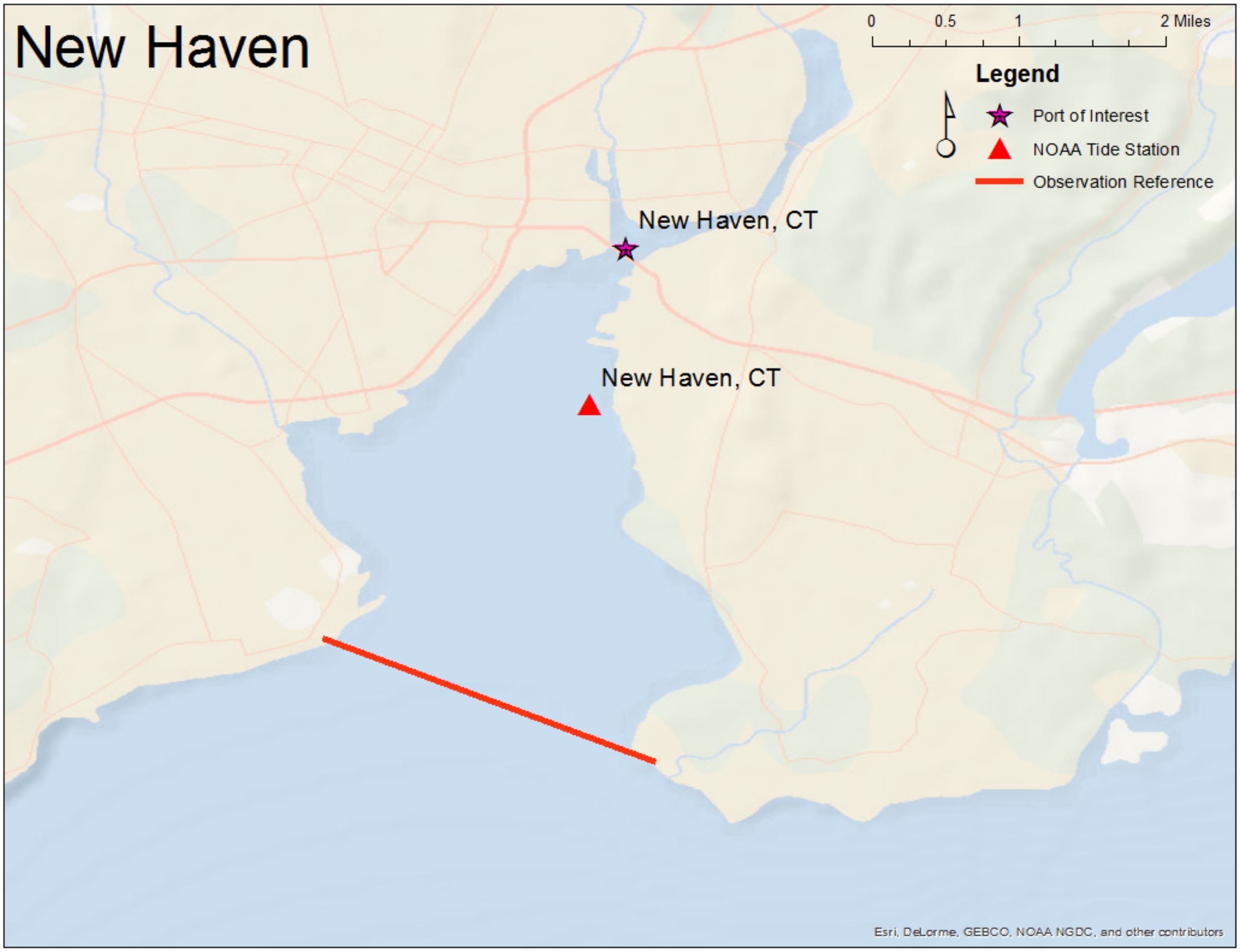

Vessel Call Frequency, Mobile, AL, 2013
MON 9 3 6 3 3 1 4 6 2 7 7 2 3 3 4 3 4 7 4 7 8 4 8 8
TUE 7 1 1 3 7 3 2 2 0 5 12 4 3 4 3 2 3 2 2 3 2 5 5 6
WED 0 3 12 4 5 2 3 5 4 5 5 3 1 2 3 4 4 5 0 5 4 5 5 6
THU 4 2 5 11 1 3 1 1 4 4 4 0 2 2 3 3 3 2 1 2 9 4 2 4
FRI 2 1 3 2 5 6 0 1 2 5 7 6 3 1 4 5 3 4 8 3 5 4 5 6
SAT 6 4 4 2 3 1 2 5 5 4 0 7 4 2 6 2 5 4 2 8 6 6 3 4
SUN 3 4 8 2 2 1 4 0 3 3 5 4 2 4 3 5 4 5 4 4 4 4 3 7
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)


Vessel Call Frequency, Mobile, AL, 2014
MON 5 1 2 5 1 3 3 1 1 4 11 7 7 6 6 5 4 6 8 8 5 2 8 7
TUE 4 3 5 4 9 4 3 5 10 0 5 4 1 4 5 4 3 5 2 7 6 4 3 3
WED 3 4 4 1 1 2 5 3 6 2 8 3 4 3 3 5 6 5 5 10 9 5 6 1
THU 2 4 7 4 5 3 3 7 3 3 9 8 5 4 4 5 4 5 6 3 1 9 4 4
FRI 6 6 5 1 3 6 5 2 3 5 6 4 1 4 5 5 3 6 4 6 7 4 0 2
SAT 2 1 4 2 3 2 2 3 5 3 2 8 4 3 6 4 4 4 2 5 3 4 5 2
SUN 1 6 9 6 3 2 1 3 2 3 3 6 4 3 5 6 5 9 5 6 2 2 5 5
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)


Mobile, AL Interarrival Times
2012
2013
2014
Frequency
Time Between Arrivals (Hours)
0.00
0.02
0.04
0.06
0.08
0.10
0
10
20
30
40



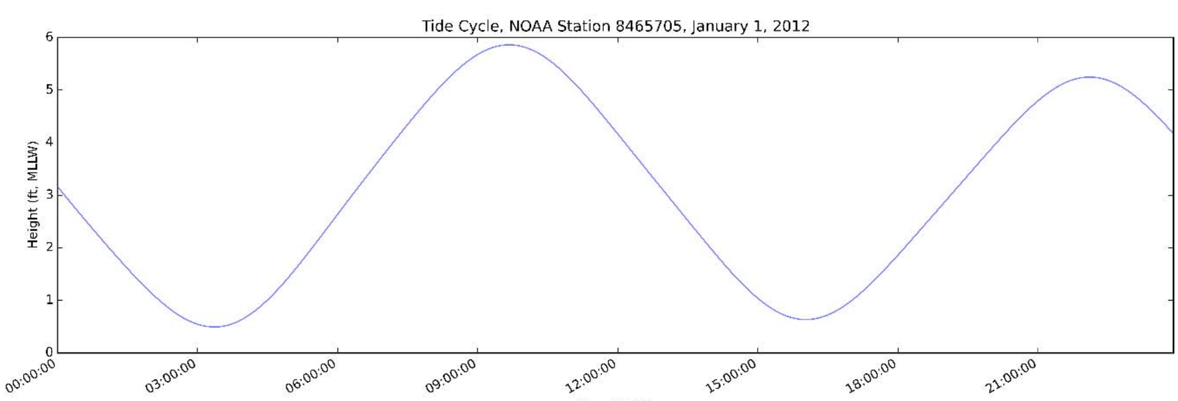
Mobile, AL Vessel Arrival Water Surface Elevation
2012
2013
2014
Frequency
Water Surface Elevation (Ft. MLLW)

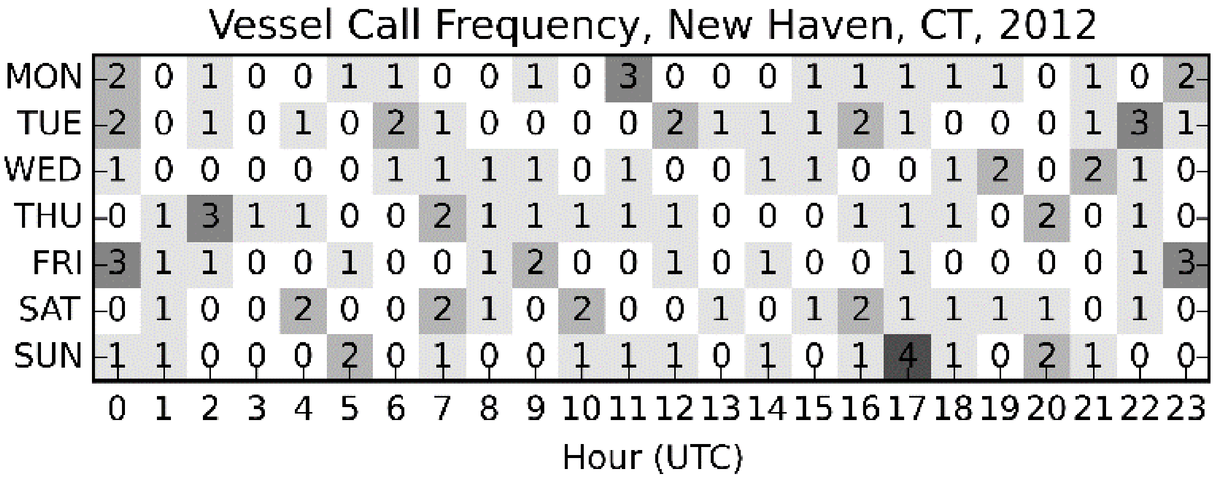


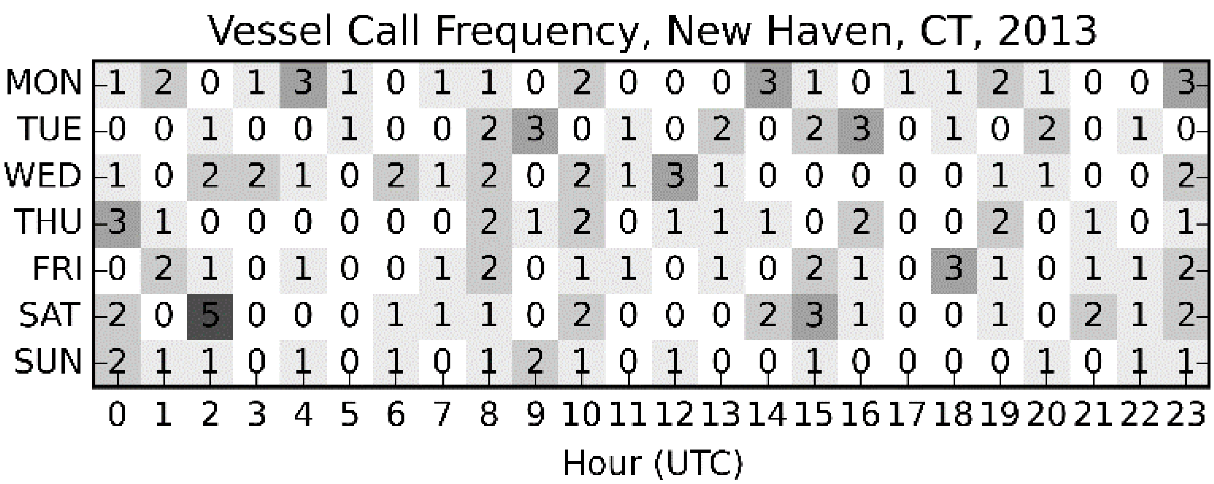
Port of Interest: **New Haven, CT**

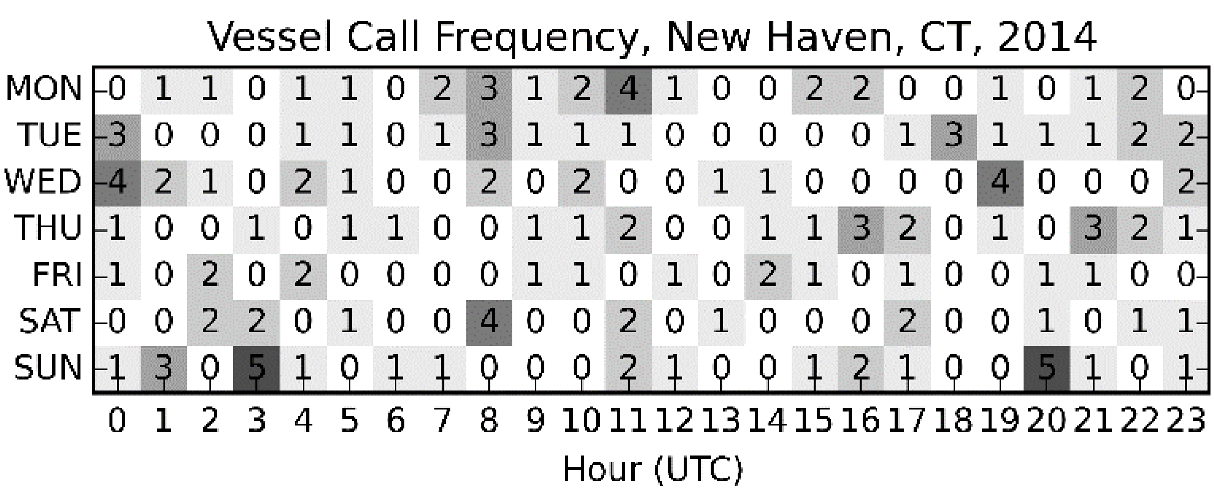
Tide Station Number: 8465705

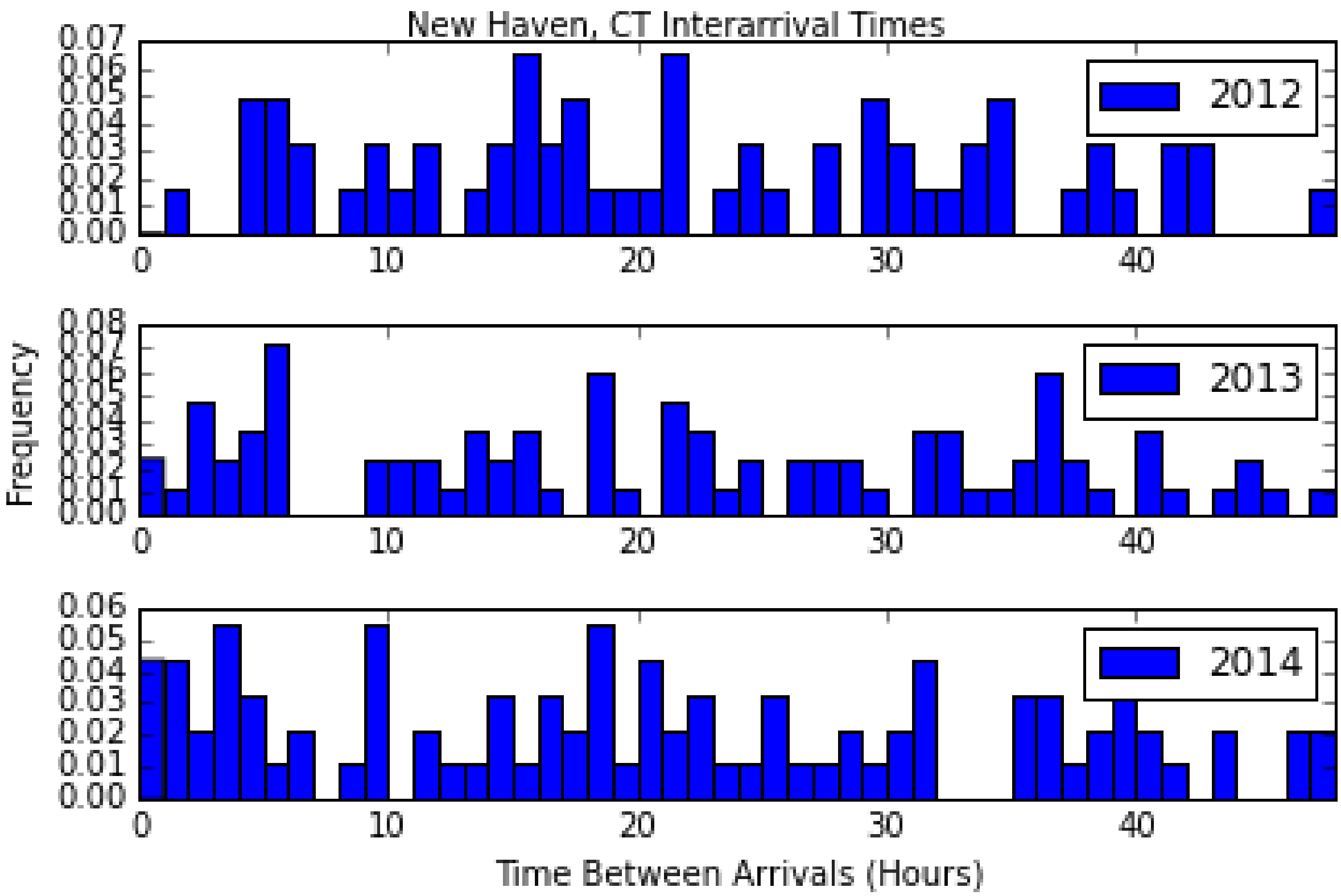
Year	Tide Range (Ft.)	Z_{25} (Ft.)	Z_{75} (Ft.)	T_{25}	T_{50}	T_{75}	TD	Arrivals
2012	9.14	1.28	5.34	0.17	0.46	0.36	0.41	121
2013	9.05	1.25	5.37	0.20	0.51	0.29	0.19	143
2014	9.20	1.23	5.39	0.19	0.48	0.32	0.26	149

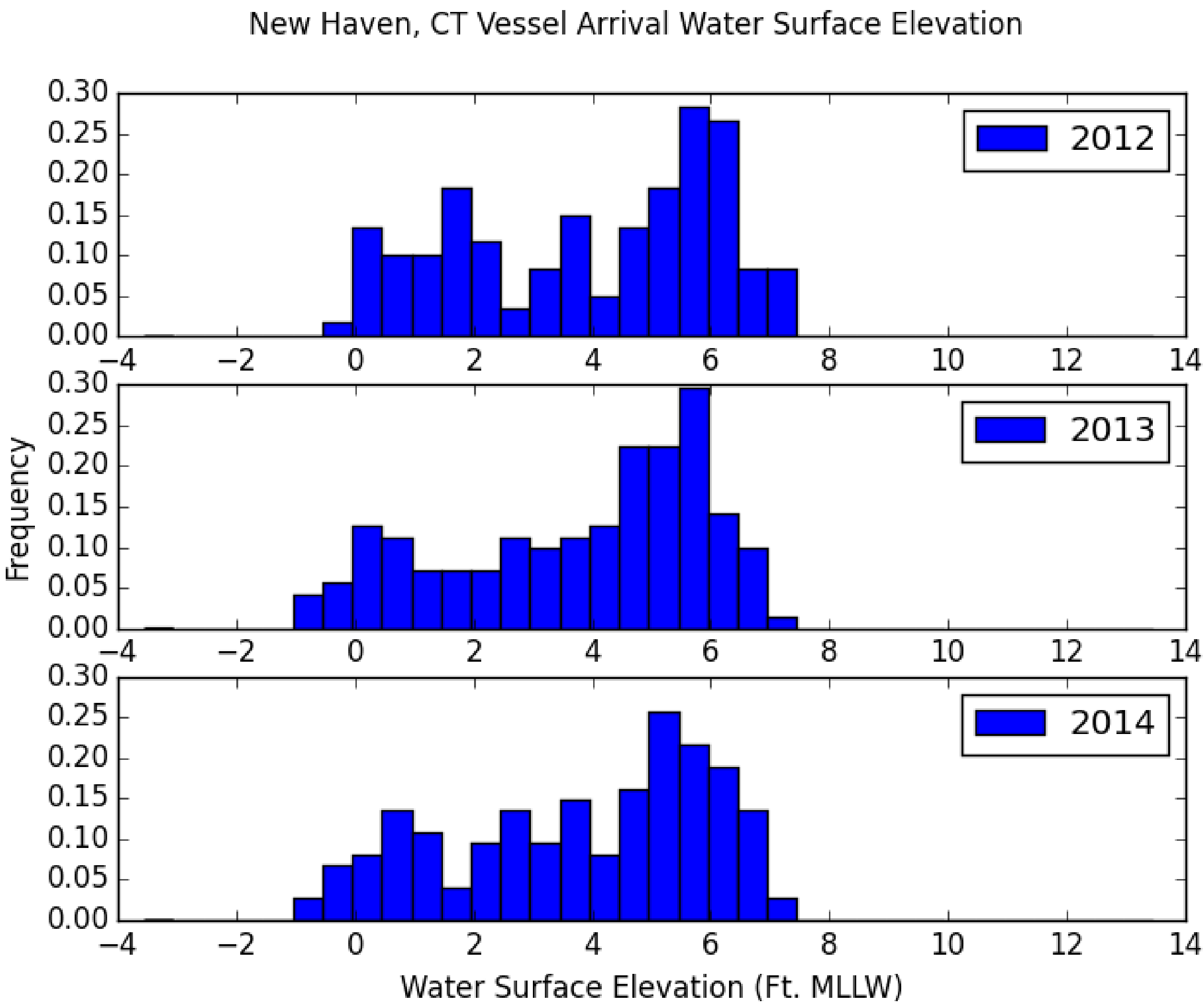



Vessel Call Frequency, New Haven, CT, 2012
MON 2 0 1 0 0 1 1 0 0 1 0 3 0 0 0 1 1 1 1 1 0 1 0 2
TUE 2 0 1 0 1 0 2 1 0 0 0 0 2 1 1 1 2 1 0 0 0 1 3 1
WED 1 0 0 0 0 0 1 1 1 1 0 1 0 0 1 1 0 0 1 2 0 2 1 0
THU 0 1 3 1 1 0 0 2 1 1 1 1 1 0 0 0 1 1 1 0 2 0 1 0
FRI 3 1 1 0 0 1 0 0 1 2 0 0 1 0 1 0 0 1 0 0 0 0 1 3
SAT 0 1 0 0 2 0 0 2 1 0 2 0 0 1 0 1 2 1 1 1 1 0 1 0
SUN 1 1 0 0 0 2 0 1 0 0 1 1 1 0 1 0 1 4 1 0 2 1 0 0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)


Vessel Call Frequency, New Haven, CT, 2013
MON 1 2 0 1 3 1 0 1 1 0 2 0 0 0 3 1 0 1 1 2 1 0 0 3
TUE 0 0 1 0 0 1 0 0 2 3 0 1 0 2 0 2 3 0 1 0 2 0 1 0
WED 1 0 2 2 1 0 2 1 2 0 2 1 3 1 0 0 0 0 0 1 1 0 0 2
THU 3 1 0 0 0 0 0 0 2 1 2 0 1 1 1 0 2 0 0 2 0 1 0 1
FRI 0 2 1 0 1 0 0 1 2 0 1 1 0 1 0 2 1 0 3 1 0 1 1 2
SAT 2 0 5 0 0 0 1 1 1 0 2 0 0 0 2 3 1 0 0 1 0 2 1 2
SUN 2 1 1 0 1 0 1 0 1 2 1 0 1 0 0 1 0 0 0 0 1 0 1 1
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)


Vessel Call Frequency, New Haven, CT, 2014
MON 0 1 1 0 1 1 0 2 3 1 2 4 1 0 0 2 2 0 0 1 0 1 2 0
TUE 3 0 0 0 1 1 0 1 3 1 1 1 0 0 0 0 0 1 3 1 1 1 2 2
WED 4 2 1 0 2 1 0 0 2 0 2 0 0 1 1 0 0 0 0 4 0 0 0 2
THU 1 0 0 1 0 1 1 0 0 1 1 2 0 0 1 1 3 2 0 1 0 3 2 1
FRI 1 0 2 0 2 0 0 0 0 1 1 0 1 0 2 1 0 1 0 0 1 1 0 0
SAT 0 0 2 2 0 1 0 0 4 0 0 2 0 1 0 0 0 2 0 0 1 0 1 1
SUN 1 3 0 5 1 0 1 1 0 0 0 2 1 0 0 1 2 1 0 0 5 1 0 1
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)


New Haven, CT Interarrival Times
2012
2013
2014
Frequency
Time Between Arrivals (Hours)
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0
10
20
30
40

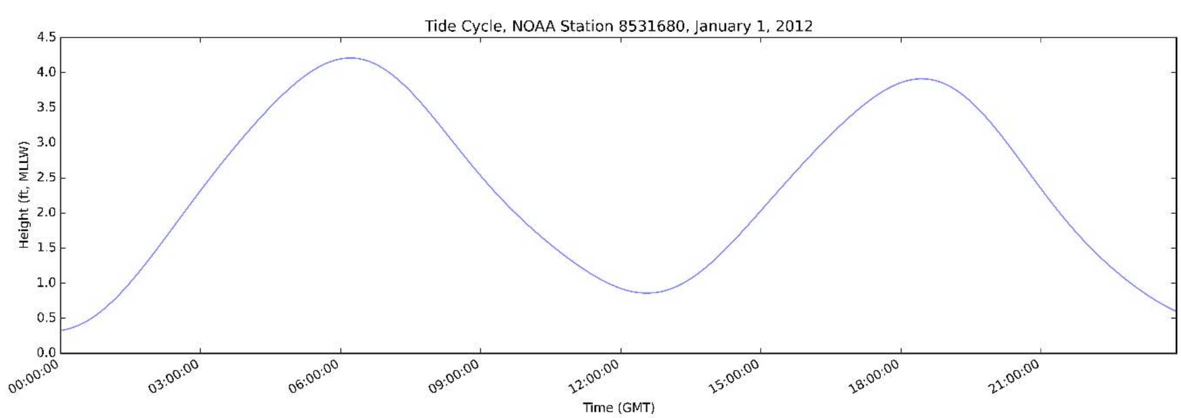


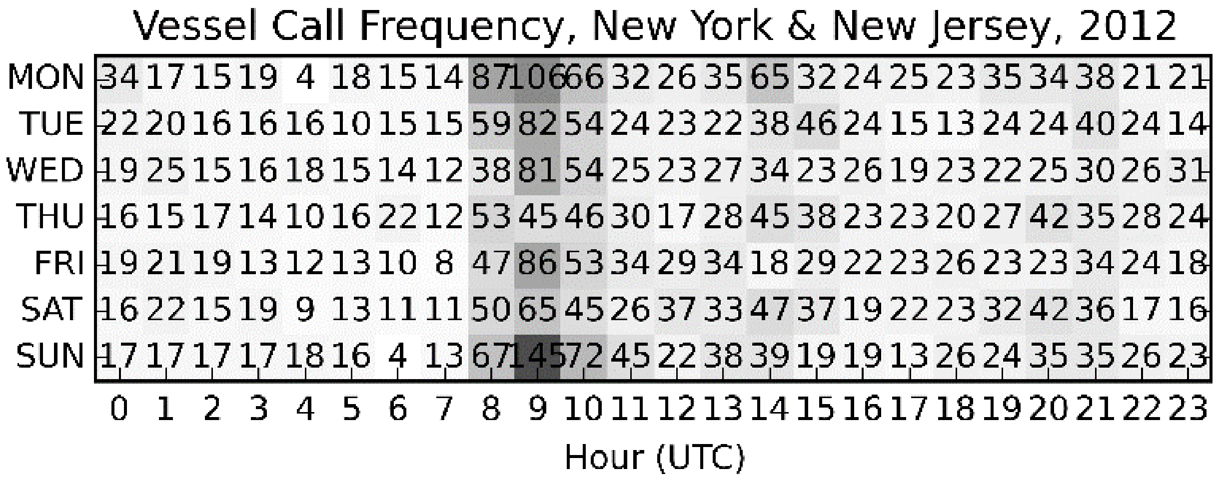
New Haven, CT Vessel Arrival Water Surface Elevation
Frequency
2012
2013
2014
Water Surface Elevation (Ft. MLLW)

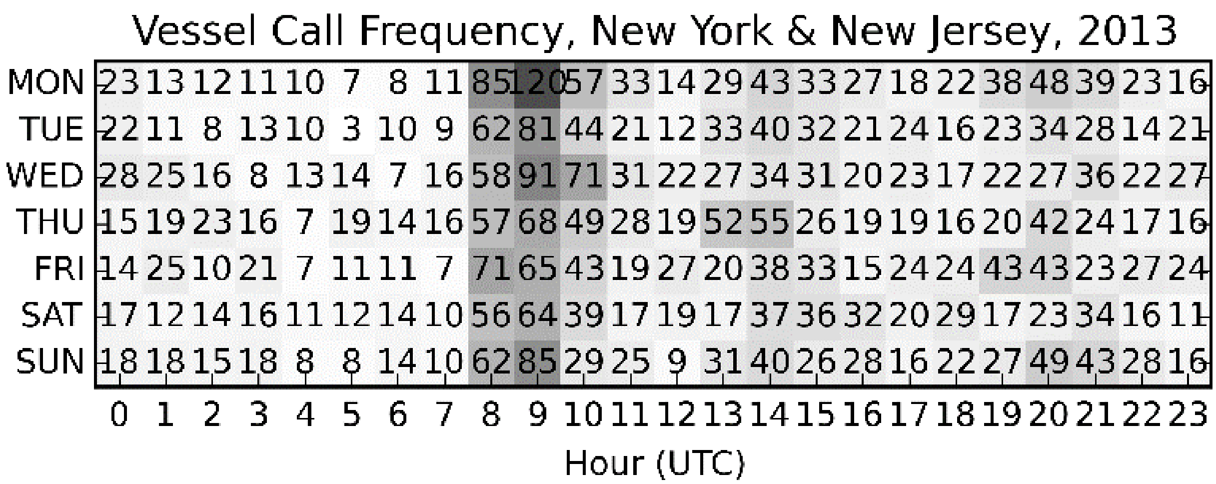
Port of Interest: **New York & New Jersey**

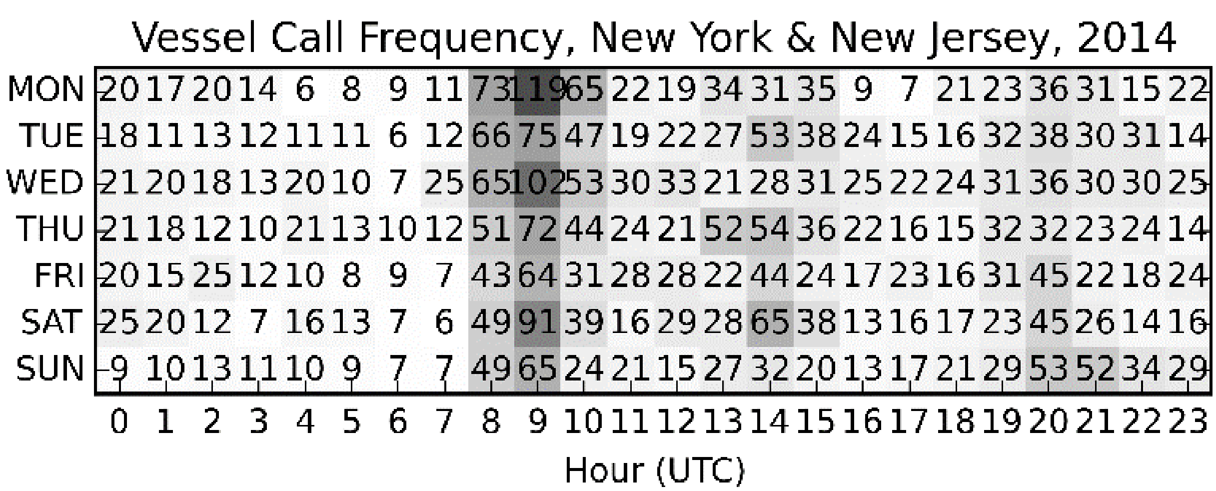
Tide Station Number: 8531680

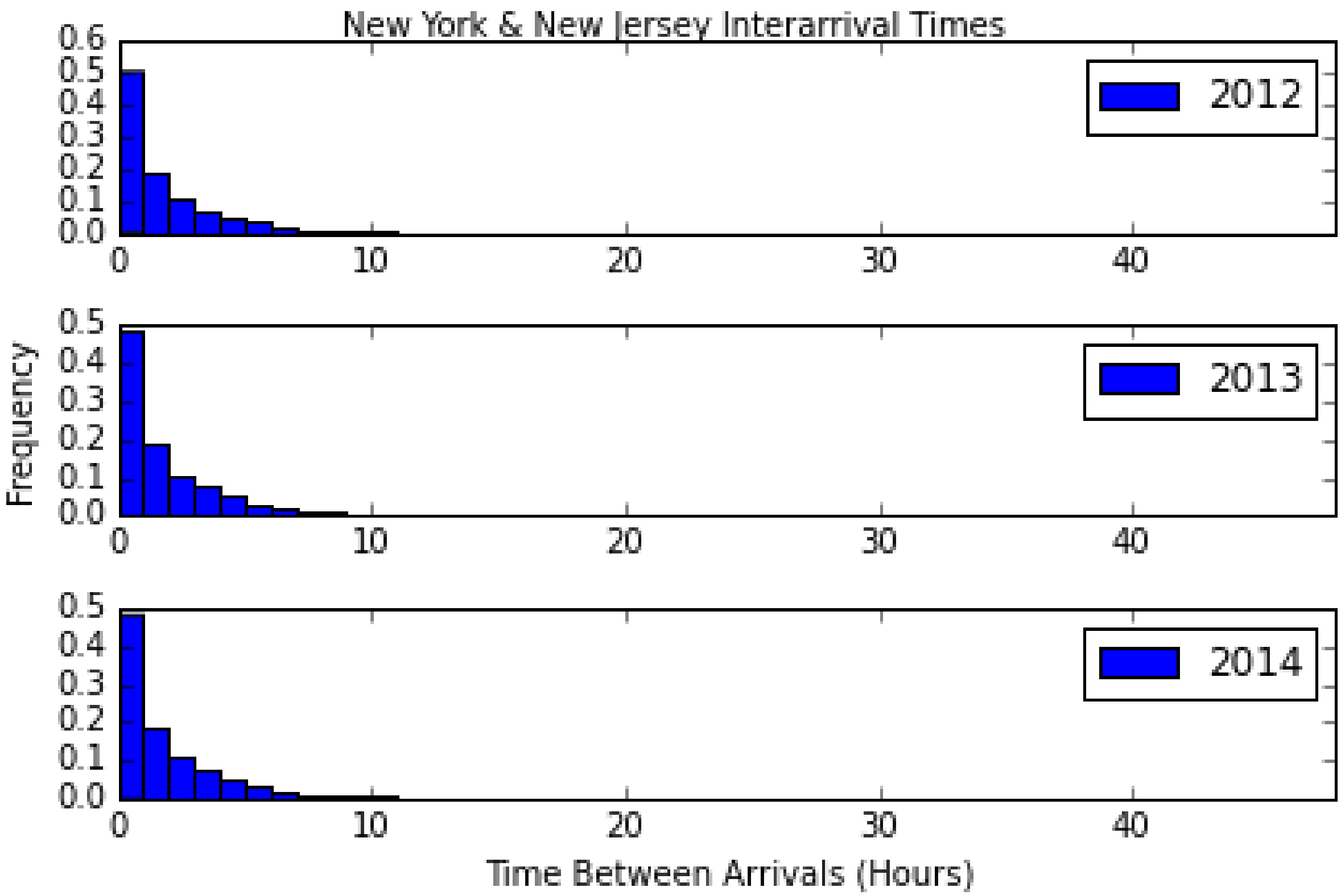
Year	Tide Range (Ft.)	Z_{25} (Ft.)	Z_{75} (Ft.)	T_{25}	T_{50}	T_{75}	TD	Arrivals
2012	7.68	1.04	4.09	0.26	0.49	0.24	-0.04	4817
2013	7.79	1.03	4.11	0.26	0.48	0.26	0.00	4537
2014	7.88	1.01	4.14	0.25	0.49	0.26	0.01	4471

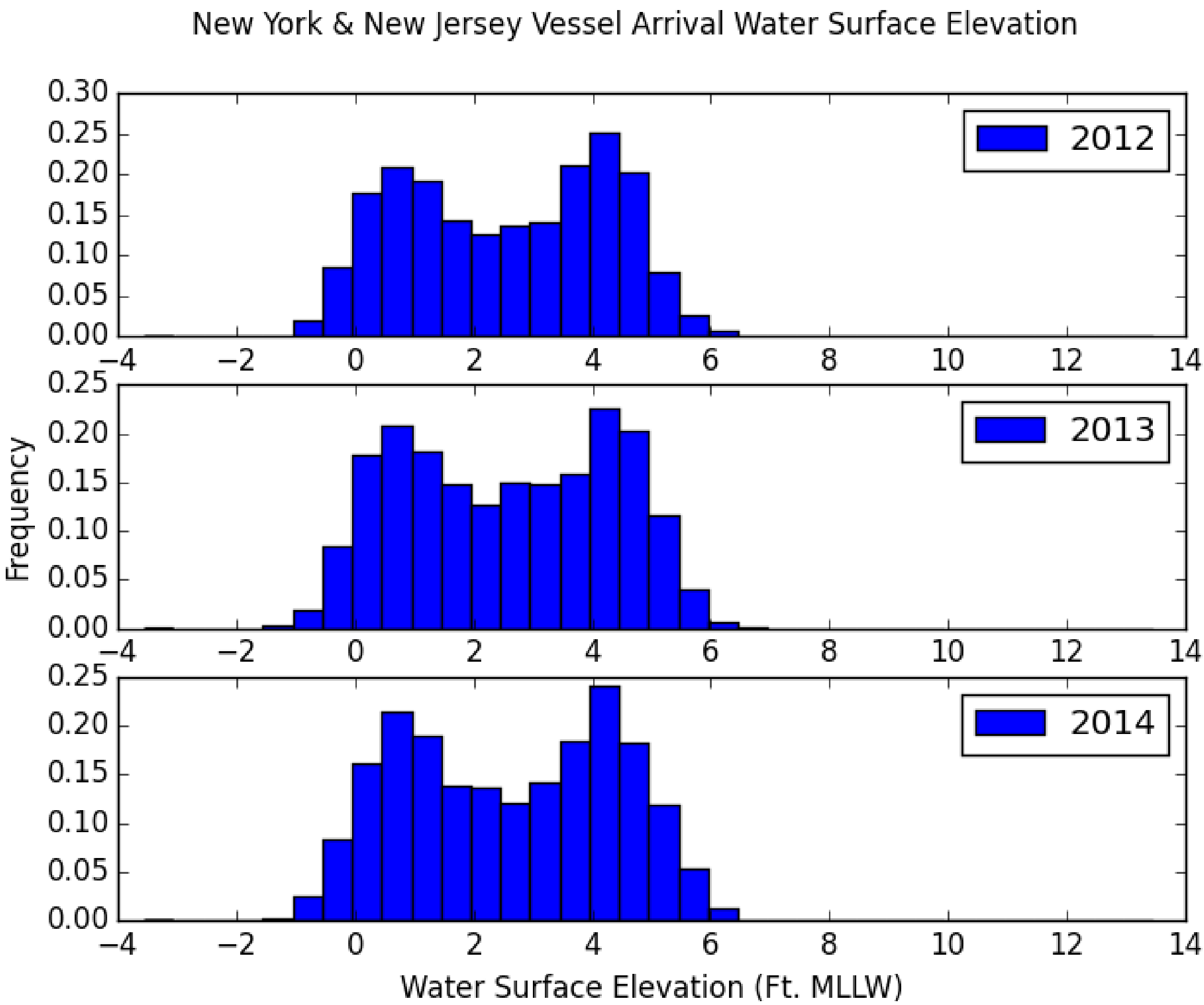



Vessel Call Frequency, New York & New Jersey, 2012
MON 34 17 15 19 4 18 15 14 87 106 66 32 26 35 65 32 24 25 23 35 34 38 21 21
TUE 22 20 16 16 16 10 15 15 59 82 54 24 23 22 38 46 24 15 13 24 24 40 24 14
WED 19 25 15 16 18 15 14 12 38 81 54 25 23 27 34 23 26 19 23 22 25 30 26 31
THU 16 15 17 14 10 16 22 12 53 45 46 30 17 28 45 38 23 23 20 27 42 35 28 24
FRI 19 21 19 13 12 13 10 8 47 86 53 34 29 34 18 29 22 23 26 23 23 34 24 18
SAT 16 22 15 19 9 13 11 11 50 65 45 26 37 33 47 37 19 22 23 32 42 36 17 16
SUN 17 17 17 17 18 16 4 13 67 145 72 45 22 38 39 19 19 13 26 24 35 35 26 23
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)

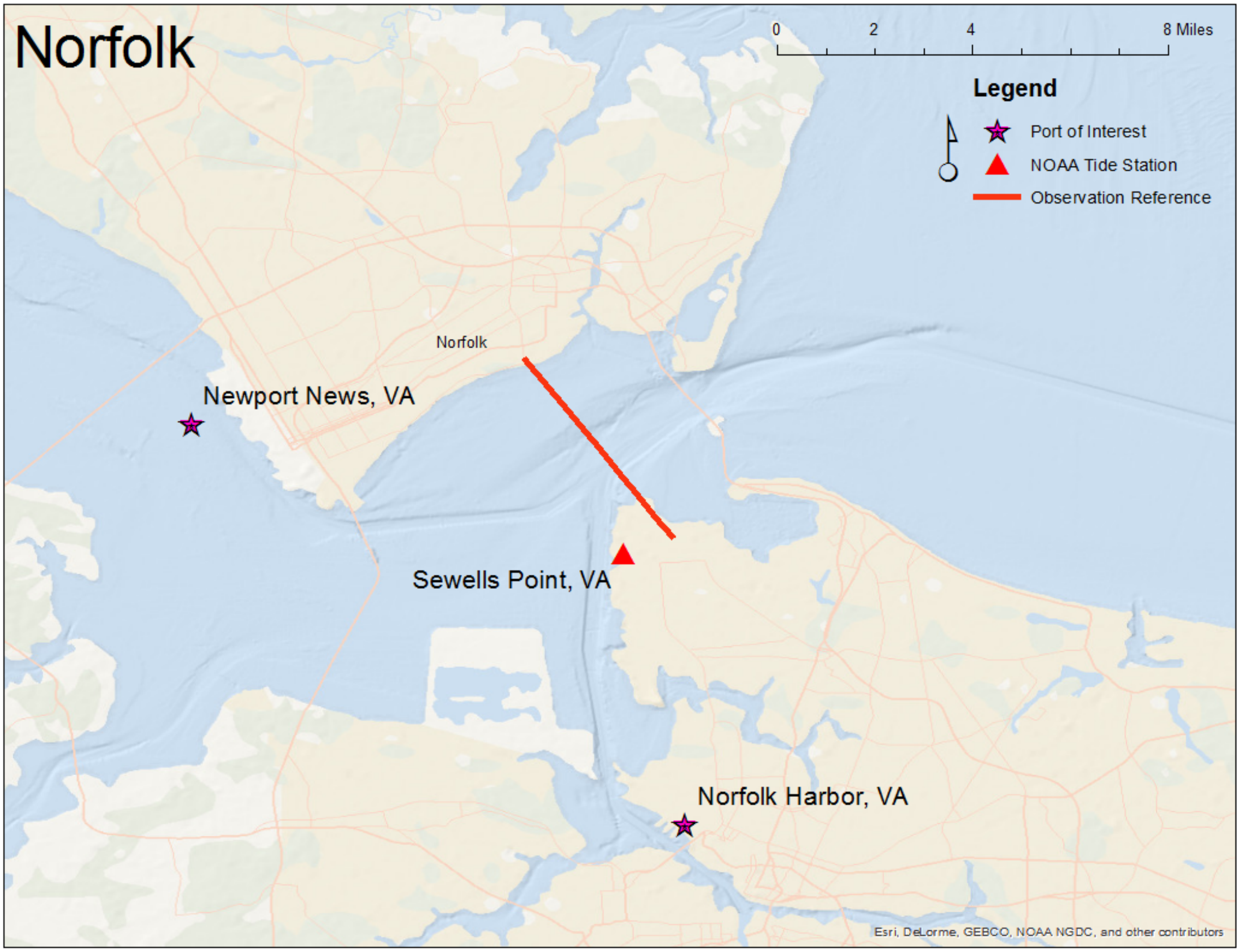

Vessel Call Frequency, New York & New Jersey, 2013
MON 23 13 12 11 10 7 8 11 85 120 57 33 14 29 43 33 27 18 22 38 48 39 23 16
TUE 22 11 8 13 10 3 10 9 62 81 44 21 12 33 40 32 21 24 16 23 34 28 14 21
WED 28 25 16 8 13 14 7 16 58 91 71 31 22 27 34 31 20 23 17 22 27 36 22 27
THU 15 19 23 16 7 19 14 16 57 68 49 28 19 52 55 26 19 19 16 20 42 24 17 16
FRI 14 25 10 21 7 11 11 7 71 65 43 19 27 20 38 33 15 24 24 43 43 23 27 24
SAT 17 12 14 16 11 12 14 10 56 64 39 17 19 17 37 36 32 20 29 17 23 34 16 11
SUN 18 18 15 18 8 8 14 10 62 85 29 25 9 31 40 26 28 16 22 27 49 43 28 16
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)


Vessel Call Frequency, New York & New Jersey, 2014
MON 20 17 20 14 6 8 9 11 73 119 65 22 19 34 31 35 9 7 21 23 36 31 15 22
TUE 18 11 13 12 11 11 6 12 66 75 47 19 22 27 53 38 24 15 16 32 38 30 31 14
WED 21 20 18 13 20 10 7 25 65 102 53 30 33 21 28 31 25 22 24 31 36 30 30 25
THU 21 18 12 10 21 13 10 12 51 72 44 24 21 52 54 36 22 16 15 32 32 23 24 14
FRI 20 15 25 12 10 8 9 7 43 64 31 28 28 22 44 24 17 23 16 31 45 22 18 24
SAT 25 20 12 7 16 13 7 6 49 91 39 16 29 28 65 38 13 16 17 23 45 26 14 16
SUN 9 10 13 11 10 9 7 7 49 65 24 21 15 27 32 20 13 17 21 29 53 52 34 29
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)


New York & New Jersey Interarrival Times
2012
2013
2014
Frequency
Time Between Arrivals (Hours)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0
10
20
30
40



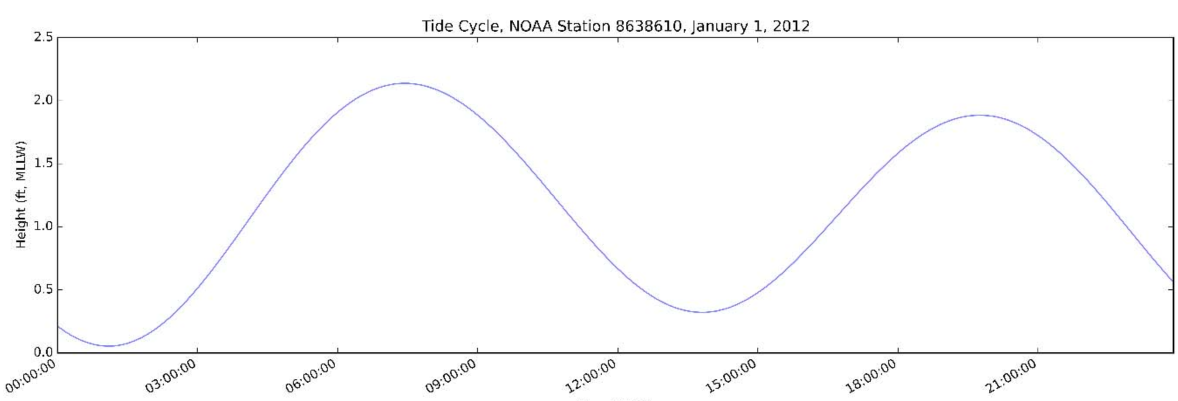
New York & New Jersey Vessel Arrival Water Surface Elevation
2012
2013
2014
Frequency
0.30
0.25
0.20
0.15
0.10
0.05
0.00
−4
−2
0
2
4
6
8
10
12
14
Water Surface Elevation (Ft. MLLW)

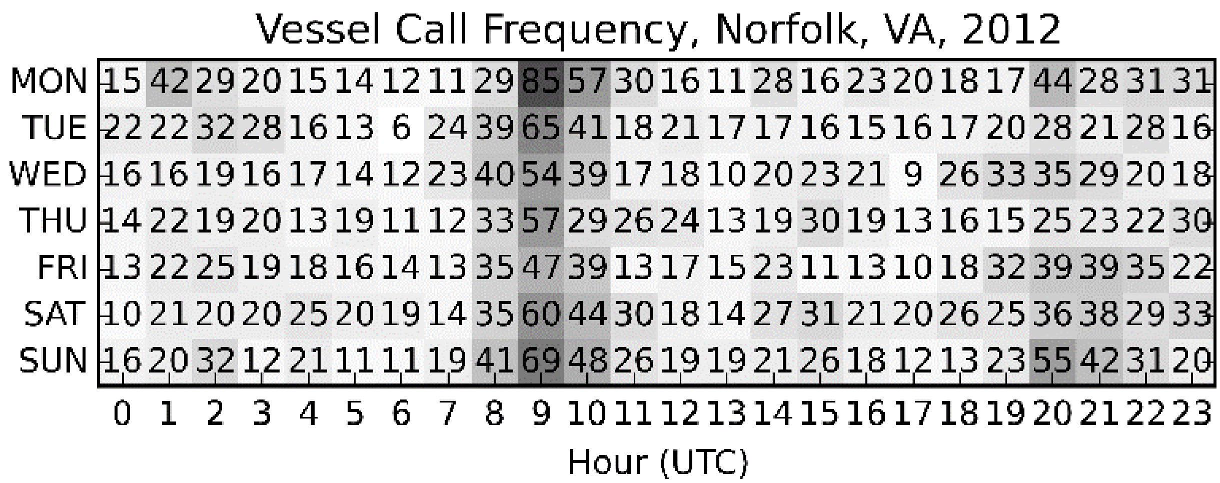


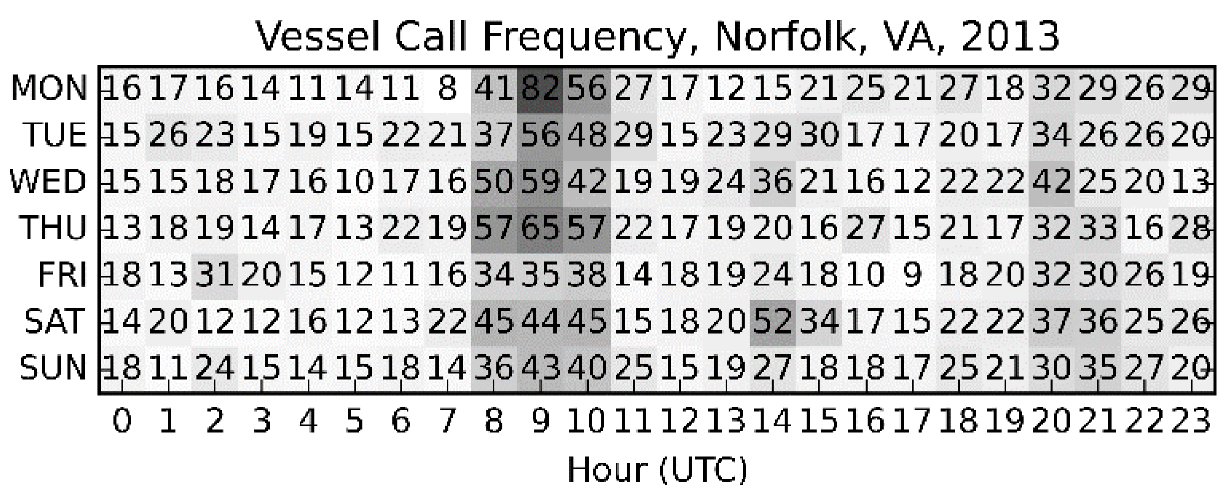
Port of Interest: **Norfolk, VA**

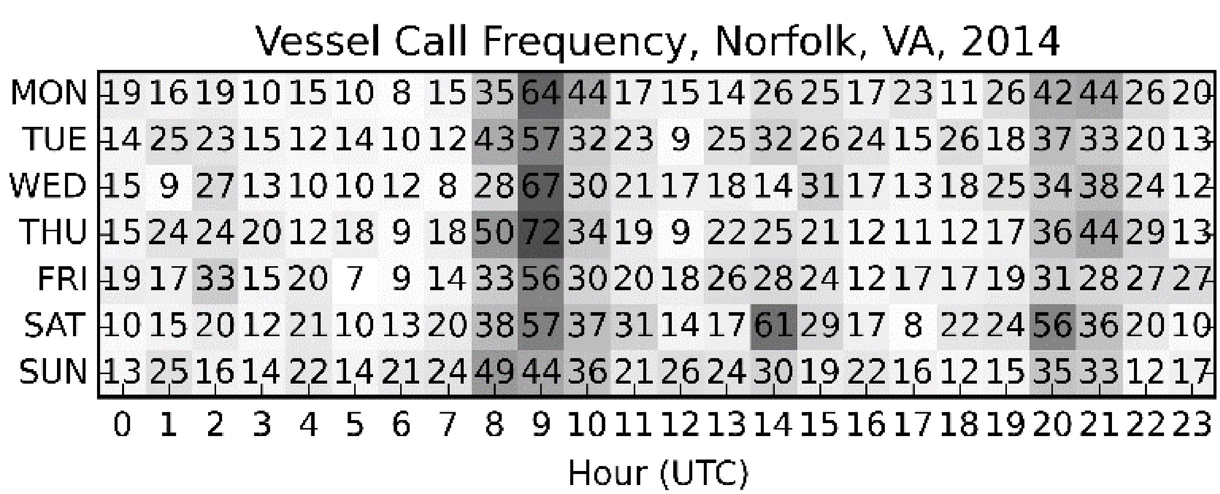
Tide Station Number: 8638610

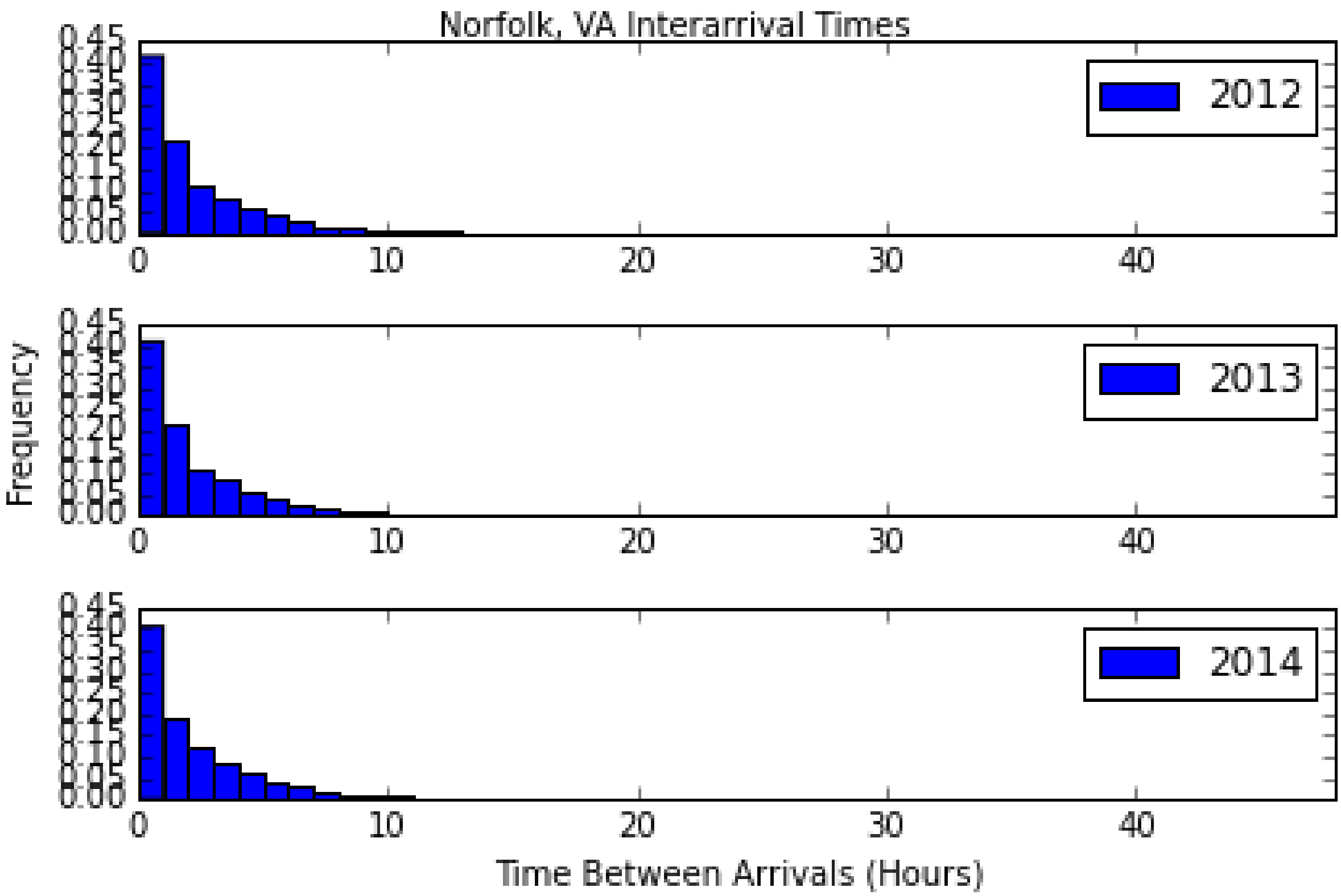
Year	Tide Range (Ft.)	Z_{25} (Ft.)	Z_{75} (Ft.)	T_{25}	T_{50}	T_{75}	TD	Arrivals
2012	4.12	0.52	2.16	0.25	0.52	0.23	-0.05	4078
2013	4.02	0.52	2.16	0.25	0.54	0.21	-0.08	3987
2014	4.21	0.51	2.18	0.25	0.51	0.24	-0.02	3901



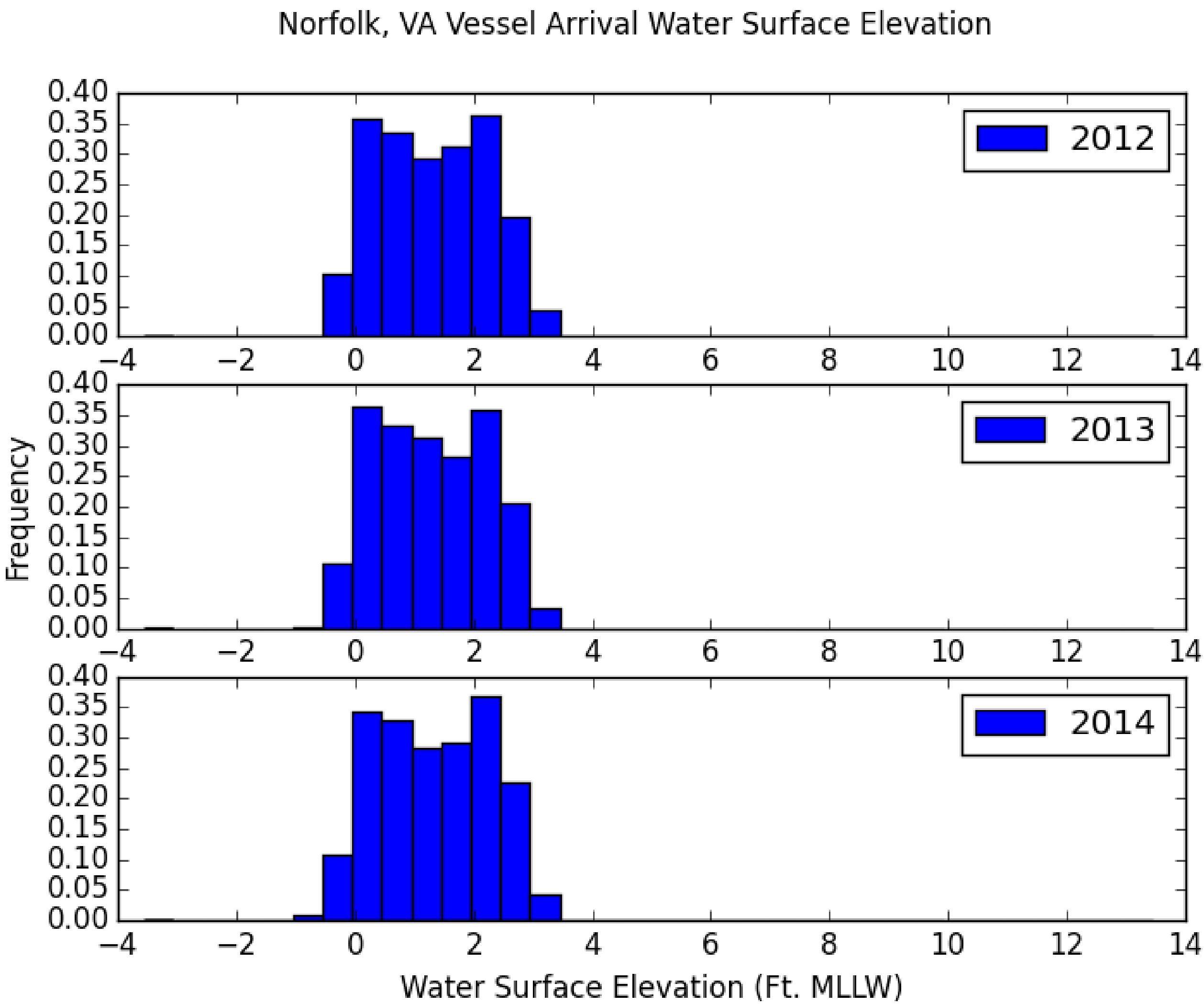

Vessel Call Frequency, Norfolk, VA, 2012
MON 15 42 29 20 15 14 12 11 29 85 57 30 16 11 28 16 23 20 18 17 44 28 31 31
TUE 22 22 32 28 16 13 6 24 39 65 41 18 21 17 17 16 15 16 17 20 28 21 28 16
WED 16 16 19 16 17 14 12 23 40 54 39 17 18 10 20 23 21 9 26 33 35 29 20 18
THU 14 22 19 20 13 19 11 12 33 57 29 26 24 13 19 30 19 13 16 15 25 23 22 30
FRI 13 22 25 19 18 16 14 13 35 47 39 13 17 15 23 11 13 10 18 32 39 39 35 22
SAT 10 21 20 20 25 20 19 14 35 60 44 30 18 14 27 31 21 20 26 25 36 38 29 33
SUN 16 20 32 12 21 11 11 19 41 69 48 26 19 19 21 26 18 12 13 23 55 42 31 20
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)


Vessel Call Frequency, Norfolk, VA, 2013
MON 16 17 16 14 11 14 11 8 41 82 56 27 17 12 15 21 25 21 27 18 32 29 26 29
TUE 15 26 23 15 19 15 22 21 37 56 48 29 15 23 29 30 17 17 20 17 34 26 26 20
WED 15 15 18 17 16 10 17 16 50 59 42 19 19 24 36 21 16 12 22 22 42 25 20 13
THU 13 18 19 14 17 13 22 19 57 65 57 22 17 19 20 16 27 15 21 17 32 33 16 28
FRI 18 13 31 20 15 12 11 16 34 35 38 14 18 19 24 18 10 9 18 20 32 30 26 19
SAT 14 20 12 12 16 12 13 22 45 44 45 15 18 20 52 34 17 15 22 22 37 36 25 26
SUN 18 11 24 15 14 15 18 14 36 43 40 25 15 19 27 18 18 17 25 21 30 35 27 20
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)


Vessel Call Frequency, Norfolk, VA, 2014
MON 19 16 19 10 15 10 8 15 35 64 44 17 15 14 26 25 17 23 11 26 42 44 26 20
TUE 14 25 23 15 12 14 10 12 43 57 32 23 9 25 32 26 24 15 26 18 37 33 20 13
WED 15 9 27 13 10 10 12 8 28 67 30 21 17 18 14 31 17 13 18 25 34 38 24 12
THU 15 24 24 20 12 18 9 18 50 72 34 19 9 22 25 21 12 11 12 17 36 44 29 13
FRI 19 17 33 15 20 7 9 14 33 56 30 20 18 26 28 24 12 17 17 19 31 28 27 27
SAT 10 15 20 12 21 10 13 20 38 57 37 31 14 17 61 29 17 8 22 24 56 36 20 10
SUN 13 25 16 14 22 14 21 24 49 44 36 21 26 24 30 19 22 16 12 15 35 33 12 17
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)



Norfolk, VA Interarrival Times
2012
2013
2014
Frequency
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0
10
20
30
40
Time Between Arrivals (Hours)

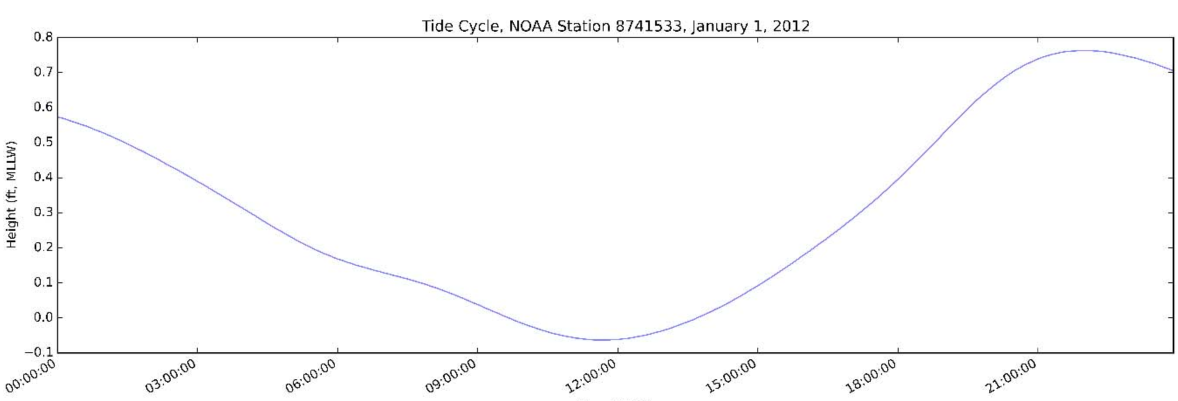


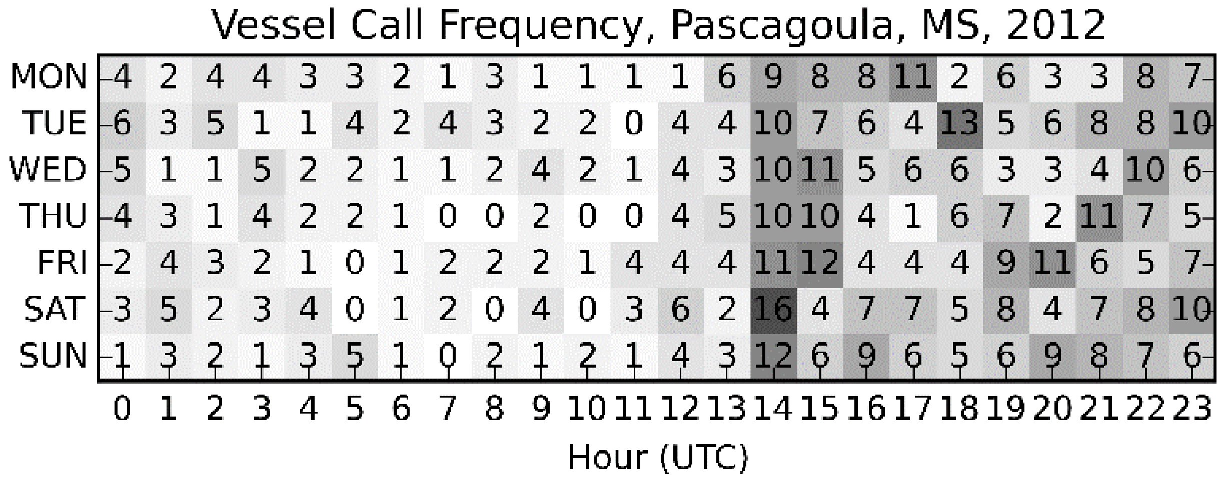
Norfolk, VA Vessel Arrival Water Surface Elevation
Frequency
2012
2013
2014
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
−4
−2
0
2
4
6
8
10
12
14
Water Surface Elevation (Ft. MLLW)

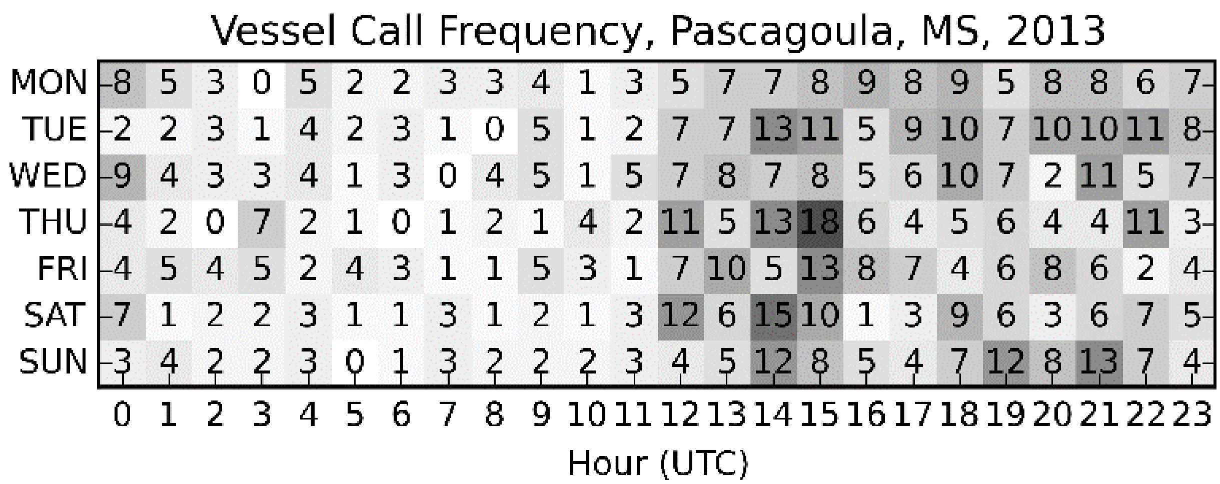
Port of Interest: **Pascagoula, MS**

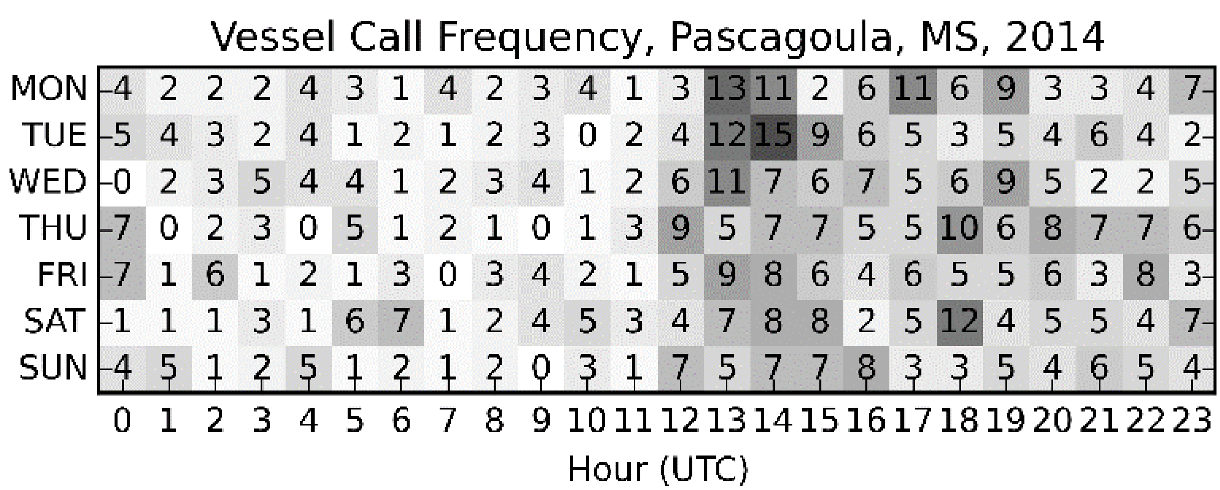
Tide Station Number: 8741533

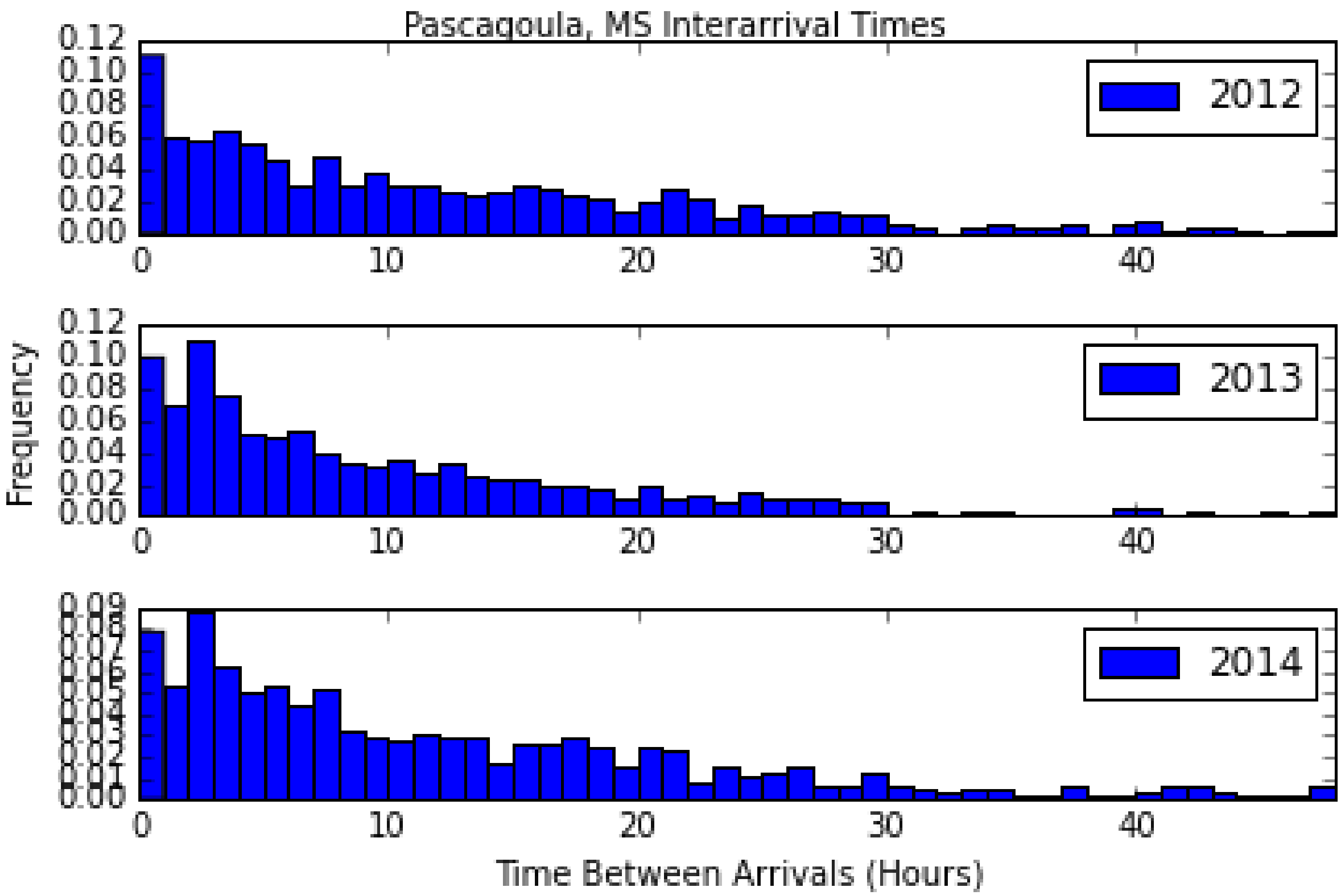
Year	Tide Range (Ft.)	Z_{25} (Ft.)	Z_{75} (Ft.)	T_{25}	T_{50}	T_{75}	TD	Arrivals
2012	3.11	0.35	1.15	0.23	0.53	0.25	0.04	727
2013	3.03	0.37	1.14	0.22	0.51	0.27	0.09	845
2014	2.86	0.38	1.13	0.23	0.54	0.24	0.02	719



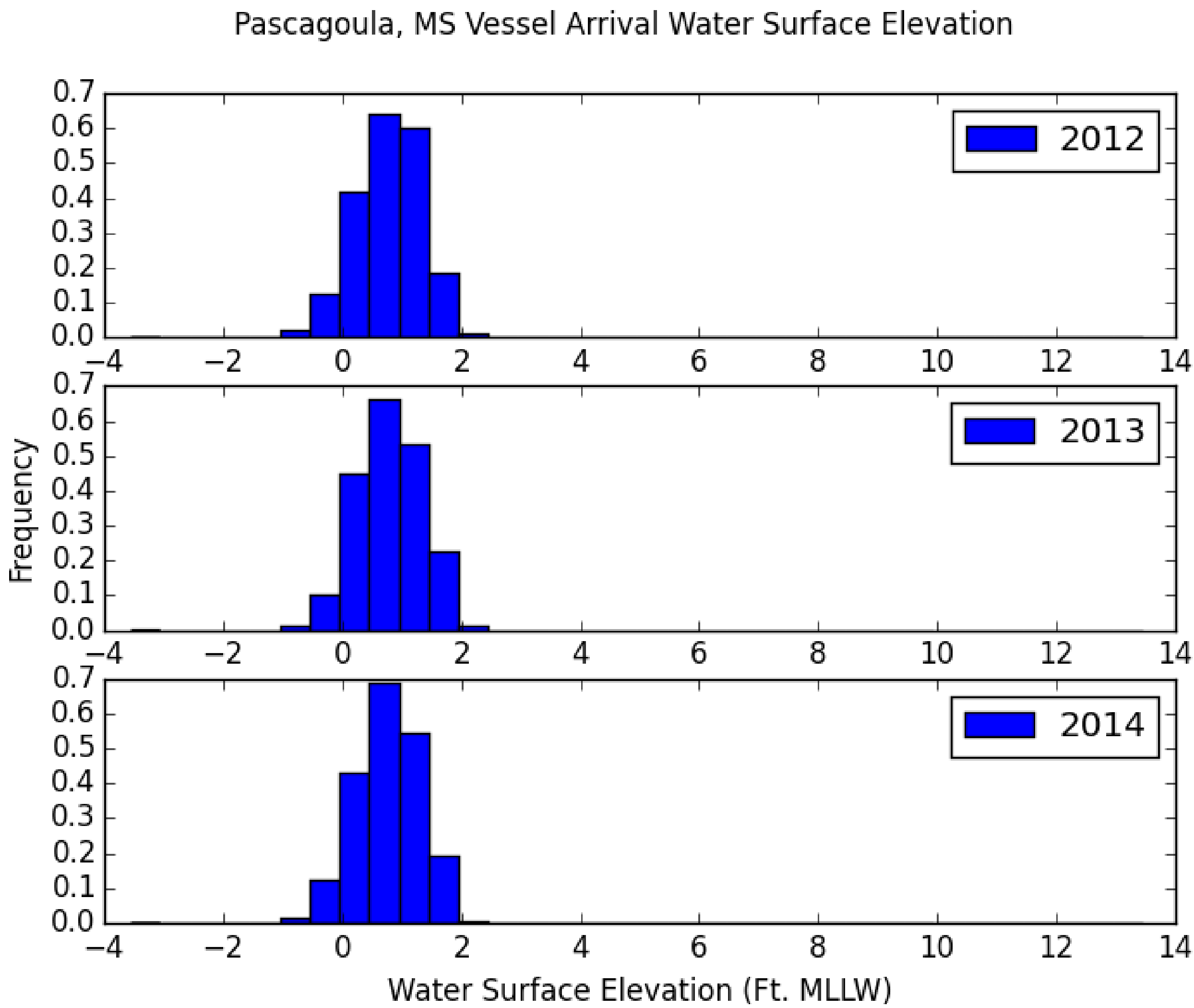

Vessel Call Frequency, Pascagoula, MS, 2012
MON 4 2 4 4 3 3 2 1 3 1 1 1 1 6 9 8 8 11 2 6 3 3 8 7
TUE 6 3 5 1 1 4 2 4 3 2 2 0 4 4 10 7 6 4 13 5 6 8 8 10
WED 5 1 1 5 2 2 1 1 2 4 2 1 4 3 10 11 5 6 6 3 3 4 10 6
THU 4 3 1 4 2 2 1 0 0 2 0 0 4 5 10 10 4 1 6 7 2 11 7 5
FRI 2 4 3 2 1 0 1 2 2 2 1 4 4 4 11 12 4 4 4 9 11 6 5 7
SAT 3 5 2 3 4 0 1 2 0 4 0 3 6 2 16 4 7 7 5 8 4 7 8 10
SUN 1 3 2 1 3 5 1 0 2 1 2 1 4 3 12 6 9 6 5 6 9 8 7 6
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)

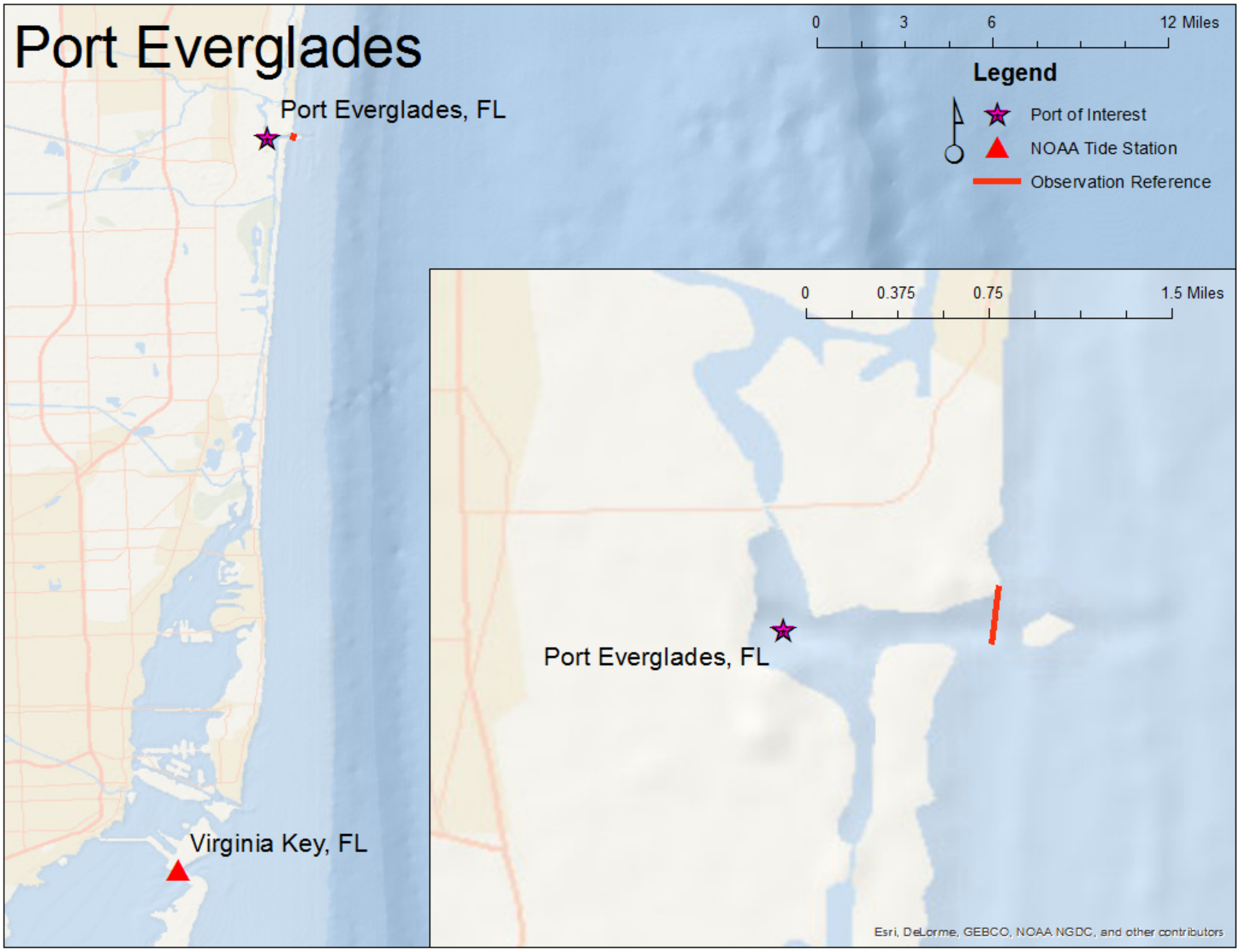

Vessel Call Frequency, Pascagoula, MS, 2013
MON 8 5 3 0 5 2 2 3 3 4 1 3 5 7 7 8 9 8 9 5 8 8 6 7
TUE 2 2 3 1 4 2 3 1 0 5 1 2 7 7 13 11 5 9 10 7 10 10 11 8
WED 9 4 3 3 4 1 3 0 4 5 1 5 7 8 7 8 5 6 10 7 2 11 5 7
THU 4 2 0 7 2 1 0 1 2 1 4 2 11 5 13 18 6 4 5 6 4 4 11 3
FRI 4 5 4 5 2 4 3 1 1 5 3 1 7 10 5 13 8 7 4 6 8 6 2 4
SAT 7 1 2 2 3 1 1 3 1 2 1 3 12 6 15 10 1 3 9 6 3 6 7 5
SUN 3 4 2 2 3 0 1 3 2 2 2 3 4 5 12 8 5 4 7 12 8 13 7 4
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)


Vessel Call Frequency, Pascagoula, MS, 2014
MON 4 2 2 2 4 3 1 4 2 3 4 1 3 13 11 2 6 11 6 9 3 3 4 7
TUE 5 4 3 2 4 1 2 1 2 3 0 2 4 12 15 9 6 5 3 5 4 6 4 2
WED 0 2 3 5 4 4 1 2 3 4 1 2 6 11 7 6 7 5 6 9 5 2 2 5
THU 7 0 2 3 0 5 1 2 1 0 1 3 9 5 7 7 5 5 10 6 8 7 7 6
FRI 7 1 6 1 2 1 3 0 3 4 2 1 5 9 8 6 4 6 5 5 6 3 8 3
SAT 1 1 1 3 1 6 7 1 2 4 5 3 4 7 8 8 2 5 12 4 5 5 4 7
SUN 4 5 1 2 5 1 2 1 2 0 3 1 7 5 7 7 8 3 3 5 4 6 5 4
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)



Pascagoula, MS Interarrival Times
2012
2013
2014
Frequency
Time Between Arrivals (Hours)
0
10
20
30
40
0.00
0.02
0.04
0.06
0.08
0.10
0.12

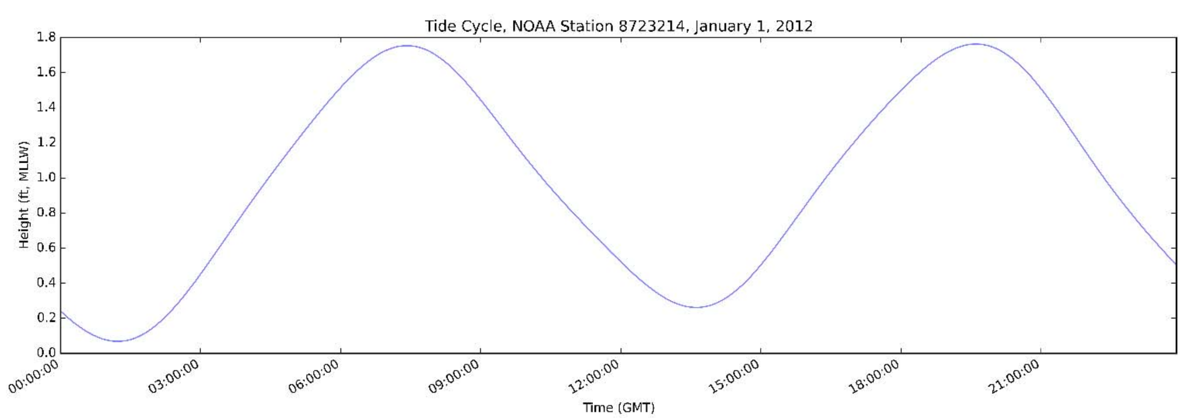

Pascagoula, MS Vessel Arrival Water Surface Elevation
2012
2013
2014
Frequency
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
−4
−2
0
2
4
6
8
10
12
14
Water Surface Elevation (Ft. MLLW)

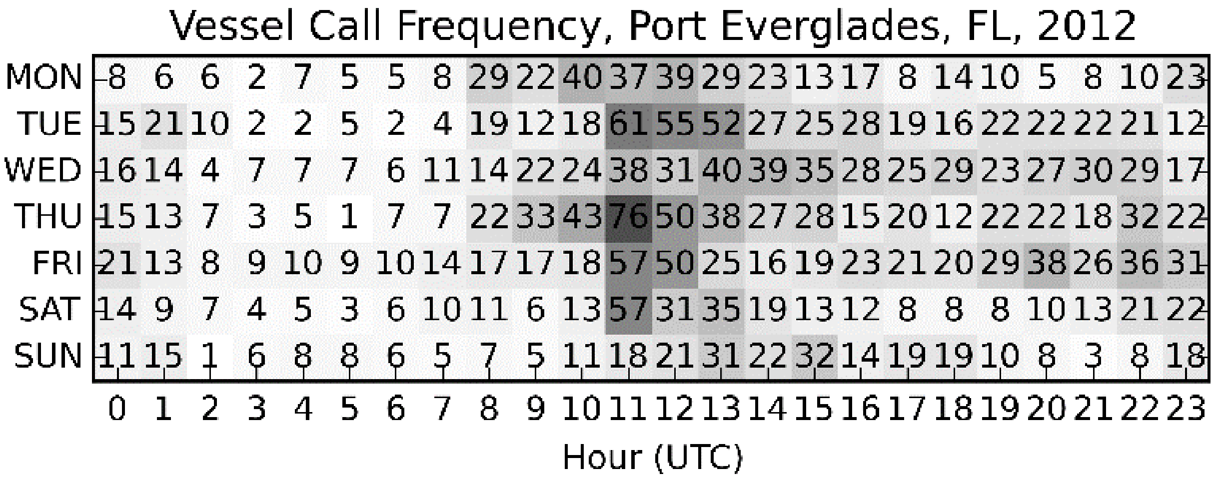


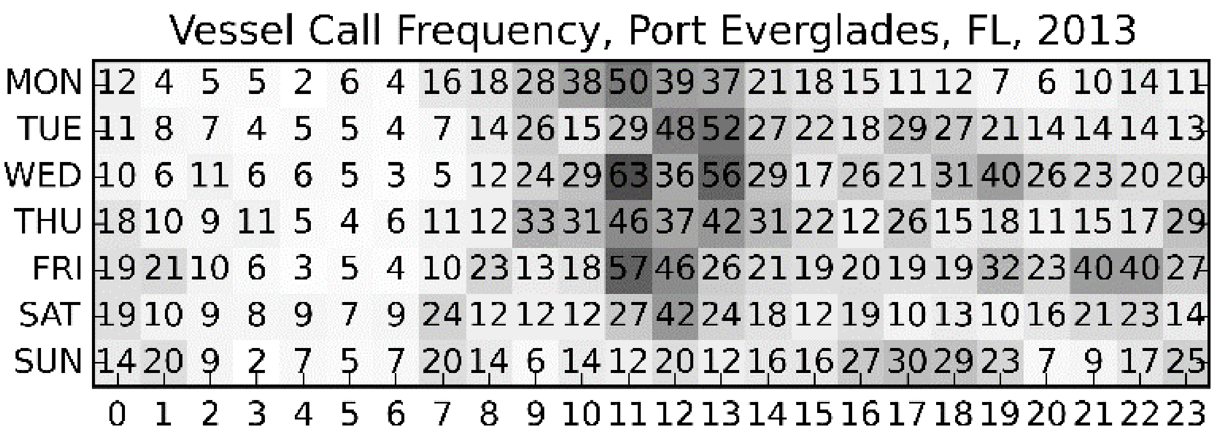
Port of Interest: **Port Everglades, FL**

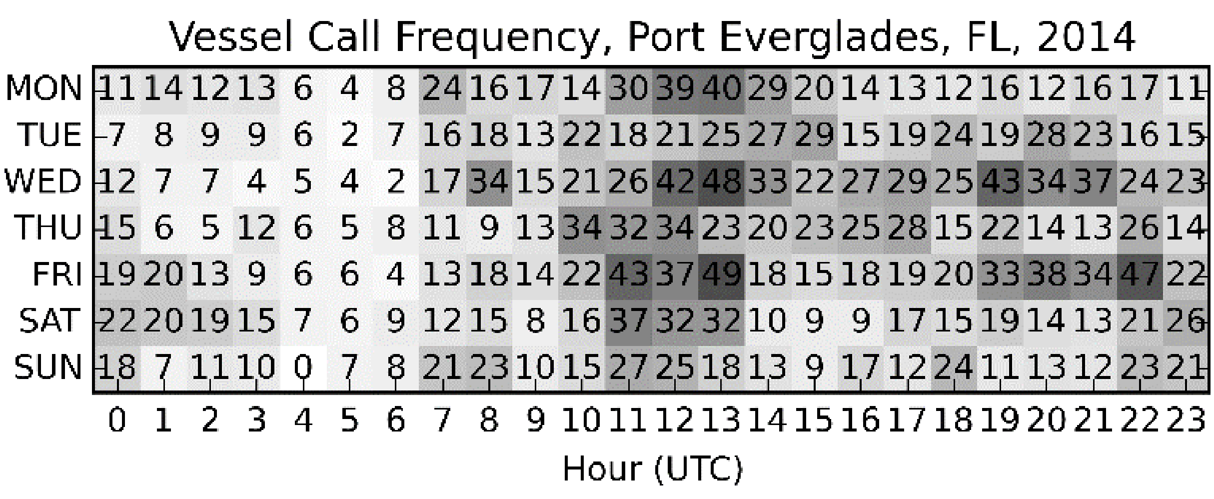
Tide Station Number: 8723214

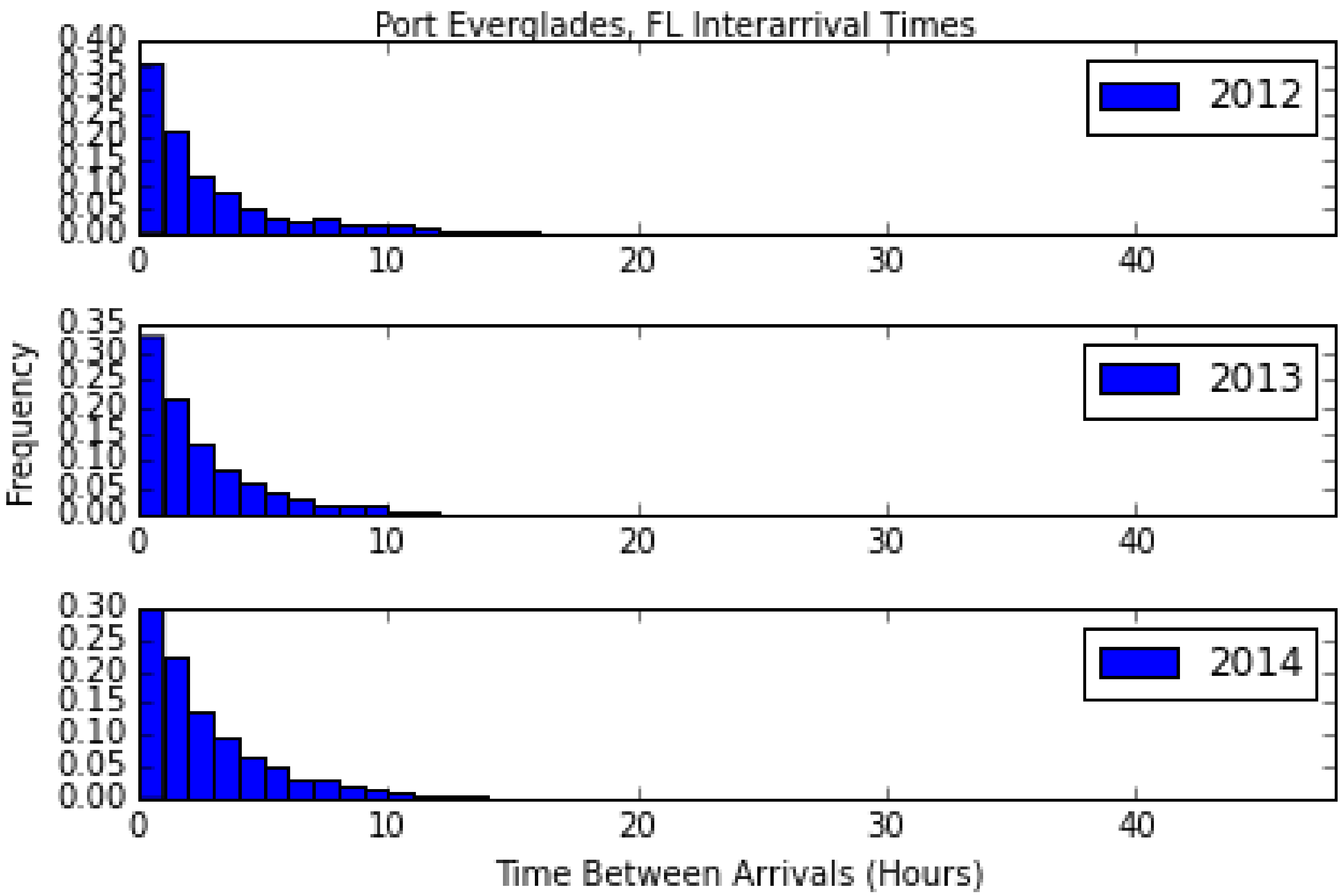
Year	Tide Range (Ft.)	Z_{25} (Ft.)	Z_{75} (Ft.)	T_{25}	T_{50}	T_{75}	TD	Arrivals
2012	3.62	0.44	1.76	0.24	0.50	0.25	0.01	3115
2013	3.57	0.44	1.76	0.26	0.49	0.25	-0.03	3081
2014	3.80	0.43	1.76	0.26	0.49	0.25	-0.02	3053



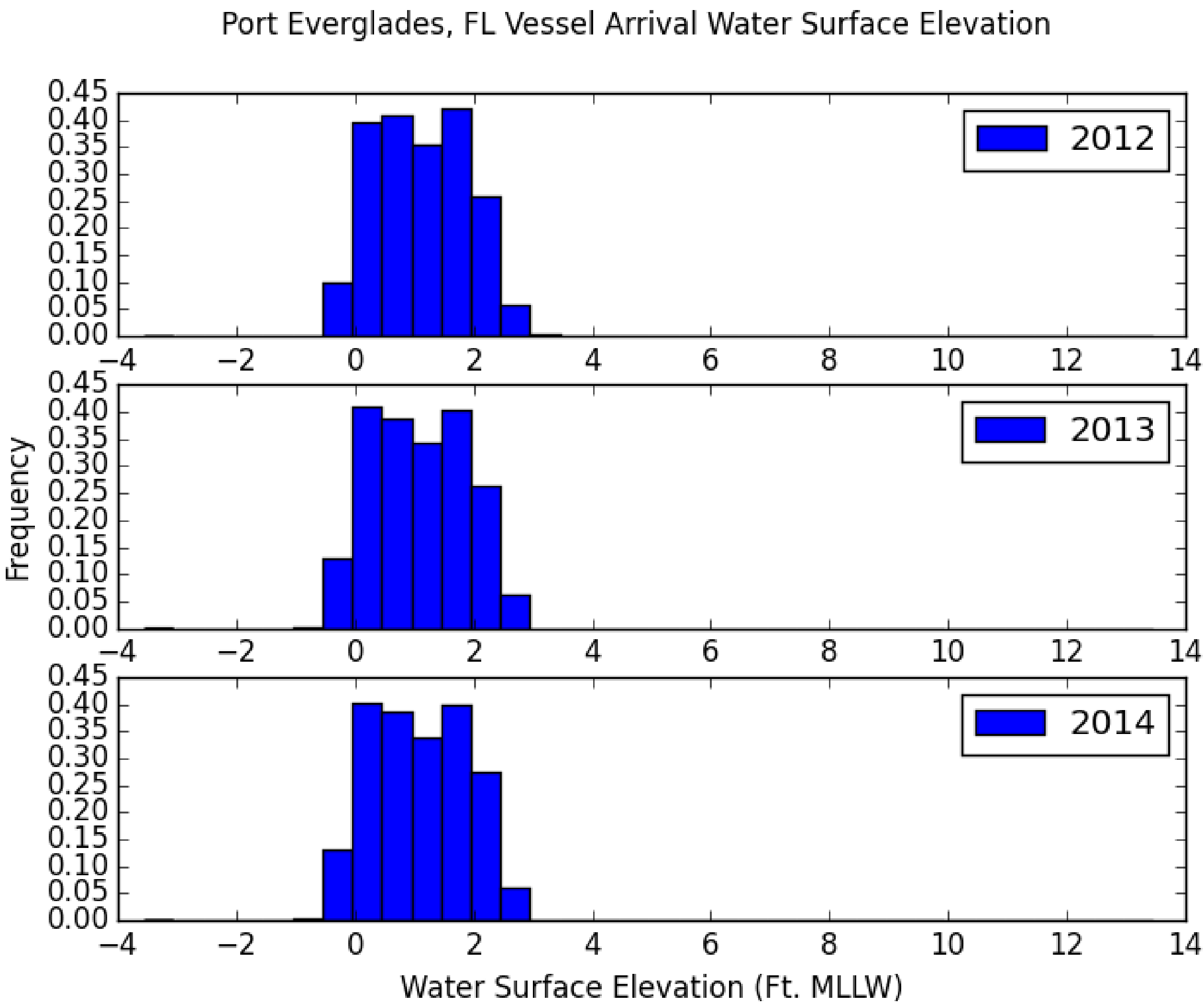

Vessel Call Frequency, Port Everglades, FL, 2012
MON 8 6 6 2 7 5 5 8 29 22 40 37 39 29 23 13 17 8 14 10 5 8 10 23
TUE 15 21 10 2 2 5 2 4 19 12 18 61 55 52 27 25 28 19 16 22 22 22 21 12
WED 16 14 4 7 7 7 6 11 14 22 24 38 31 40 39 35 28 25 29 23 27 30 29 17
THU 15 13 7 3 5 1 7 7 22 33 43 76 50 38 27 28 15 20 12 22 22 18 32 22
FRI 21 13 8 9 10 9 10 14 17 17 18 57 50 25 16 19 23 21 20 29 38 26 36 31
SAT 14 9 7 4 5 3 6 10 11 6 13 57 31 35 19 13 12 8 8 8 10 13 21 22
SUN 11 15 1 6 8 8 6 5 7 5 11 18 21 31 22 32 14 19 19 10 8 3 8 18
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)

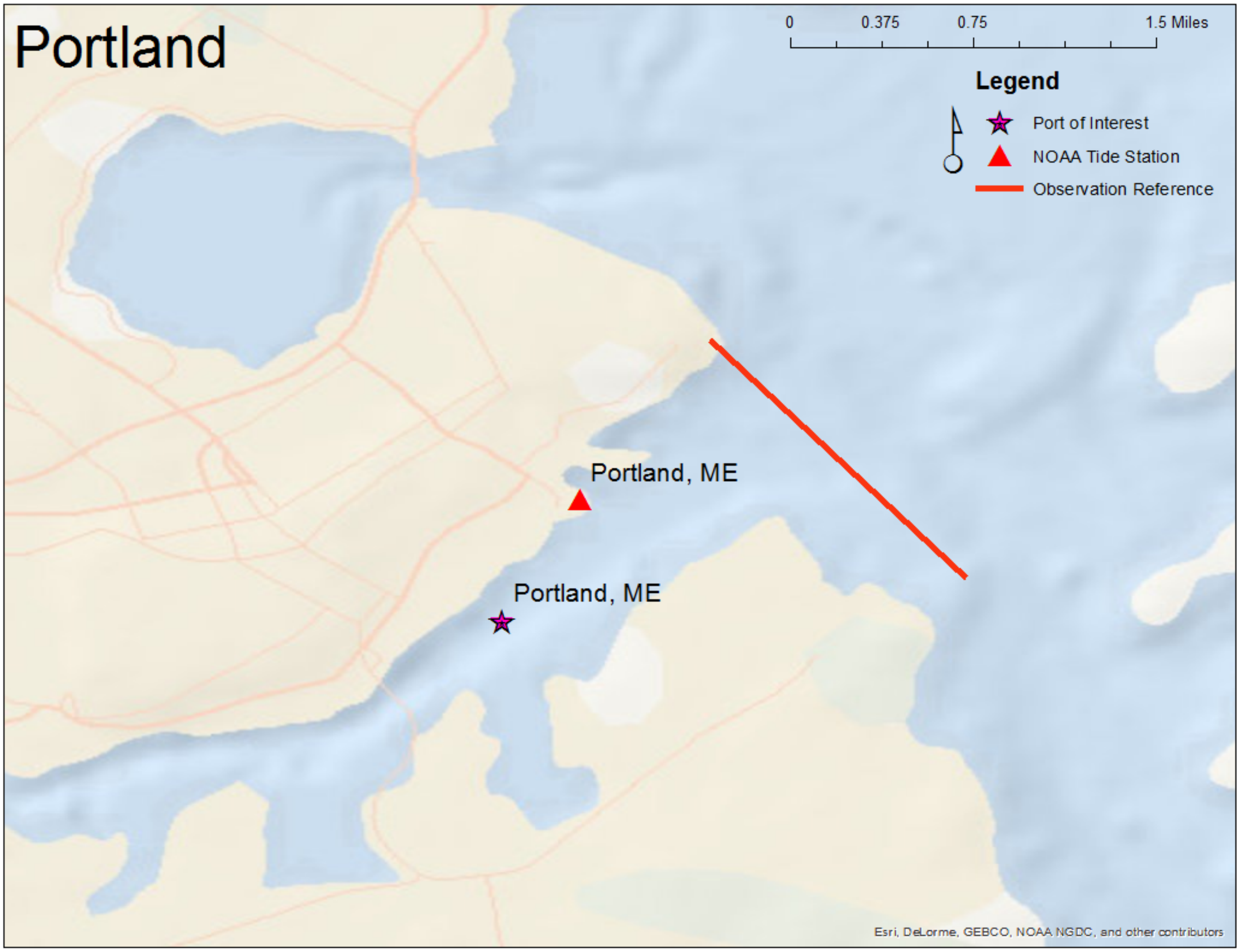

Vessel Call Frequency, Port Everglades, FL, 2013
MON 12 4 5 5 2 6 4 16 18 28 38 50 39 37 21 18 15 11 12 7 6 10 14 11
TUE 11 8 7 4 5 5 4 7 14 26 15 29 48 52 27 22 18 29 27 21 14 14 14 13
WED 10 6 11 6 6 5 3 5 12 24 29 63 36 56 29 17 26 21 31 40 26 23 20 20
THU 18 10 9 11 5 4 6 11 12 33 31 46 37 42 31 22 12 26 15 18 11 15 17 29
FRI 19 21 10 6 3 5 4 10 23 13 18 57 46 26 21 19 20 19 19 32 23 40 40 27
SAT 19 10 9 8 9 7 9 24 12 12 12 27 42 24 18 12 19 10 13 10 16 21 23 14
SUN 14 20 9 2 7 5 7 20 14 6 14 12 20 12 16 16 27 30 29 23 7 9 17 25
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23


Vessel Call Frequency, Port Everglades, FL, 2014
MON 11 14 12 13 6 4 8 24 16 17 14 30 39 40 29 20 14 13 12 16 12 16 17 11
TUE 7 8 9 9 6 2 7 16 18 13 22 18 21 25 27 29 15 19 24 19 28 23 16 15
WED 12 7 7 4 5 4 2 17 34 15 21 26 42 48 33 22 27 29 25 43 34 37 24 23
THU 15 6 5 12 6 5 8 11 9 13 34 32 34 23 20 23 25 28 15 22 14 13 26 14
FRI 19 20 13 9 6 6 4 13 18 14 22 43 37 49 18 15 18 19 20 33 38 34 47 22
SAT 22 20 19 15 7 6 9 12 15 8 16 37 32 32 10 9 9 17 15 19 14 13 21 26
SUN 18 7 11 10 0 7 8 21 23 10 15 27 25 18 13 9 17 12 24 11 13 12 23 21
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)



Port Everglades, FL Interarrival Times
2012
2013
2014
Frequency
Time Between Arrivals (Hours)

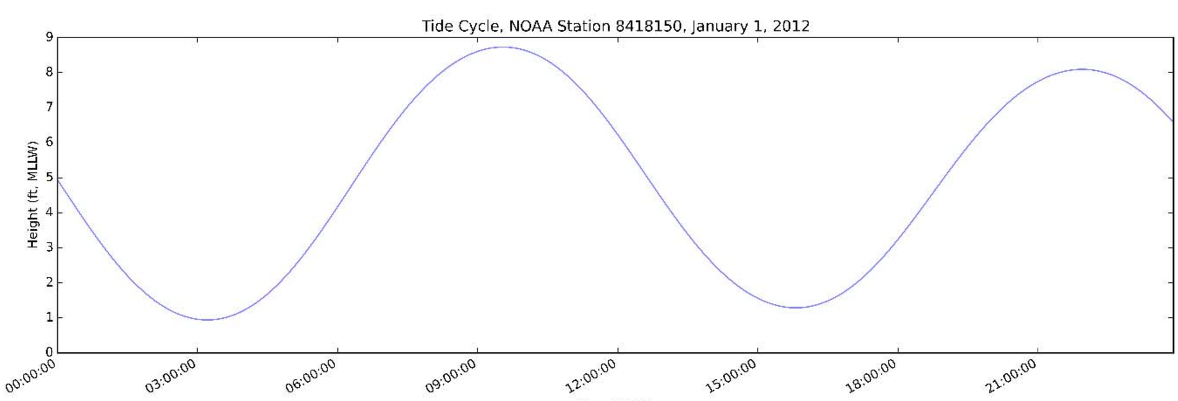

Port Everglades, FL Vessel Arrival Water Surface Elevation
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
−4
−2
0
2
4
6
8
10
12
14
2012
2013
2014
Frequency
Water Surface Elevation (Ft. MLLW)

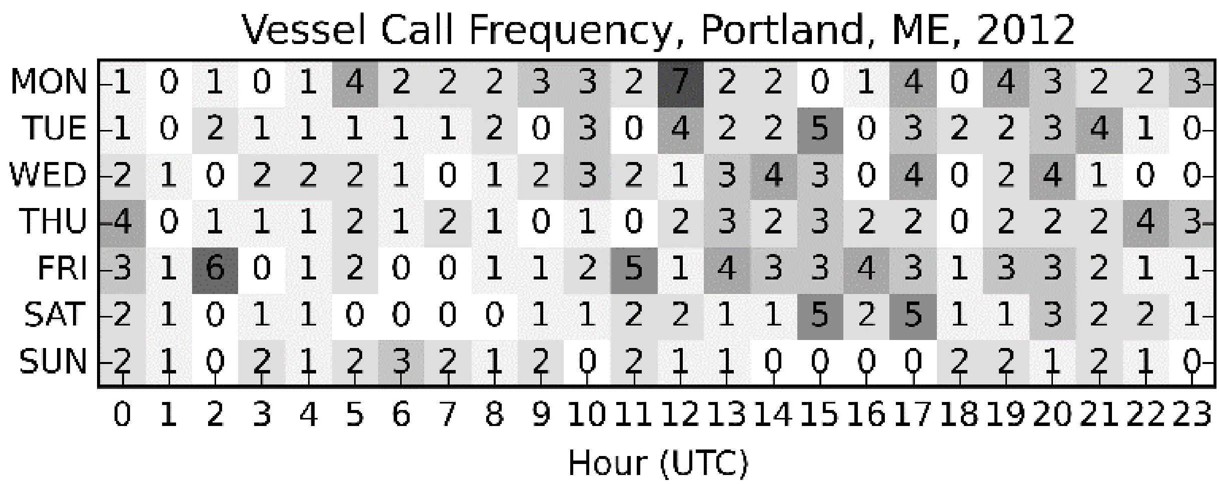


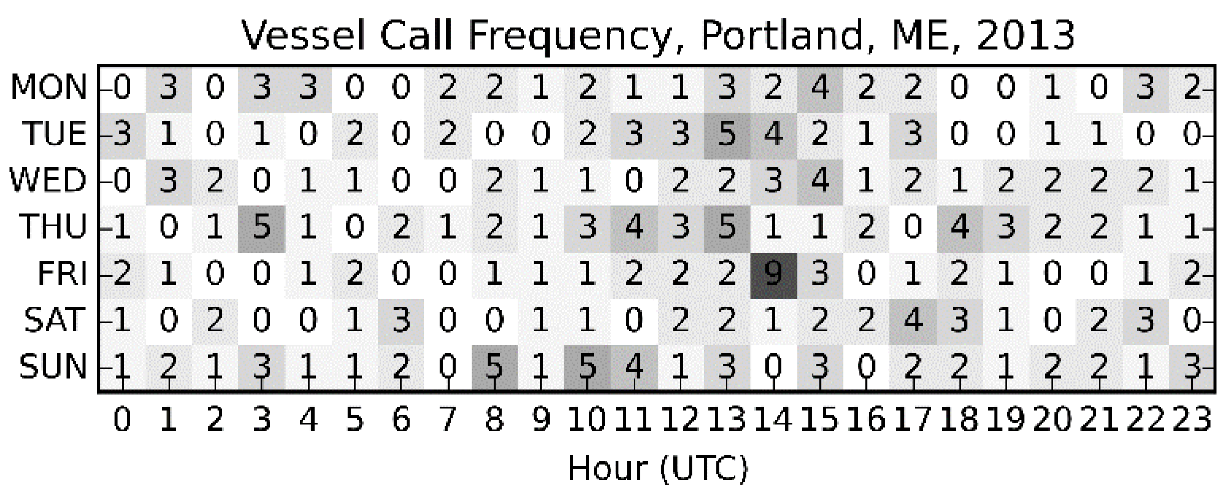
Port of Interest: **Portland, ME**

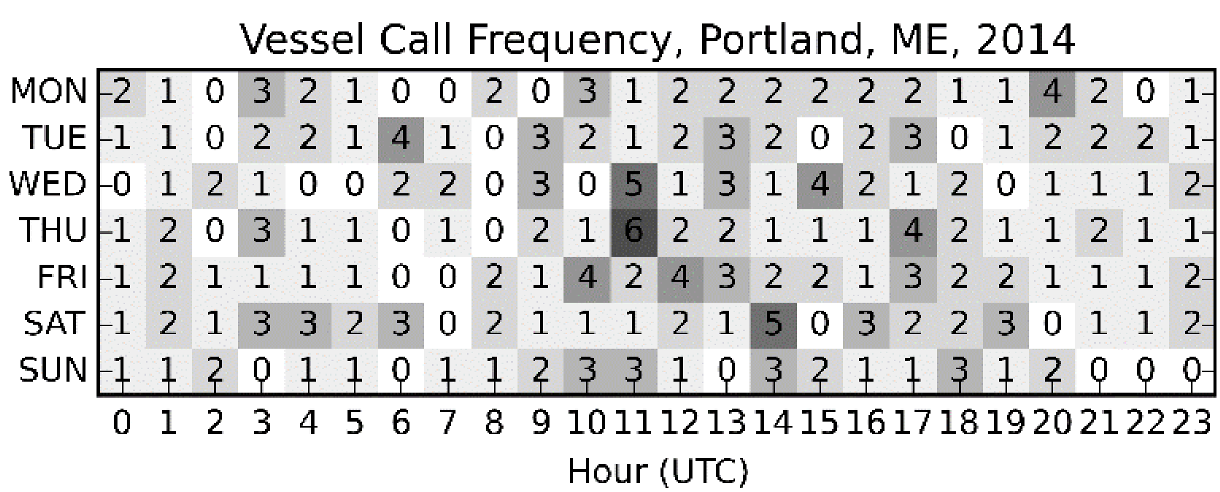
Tide Station Number: 8418150

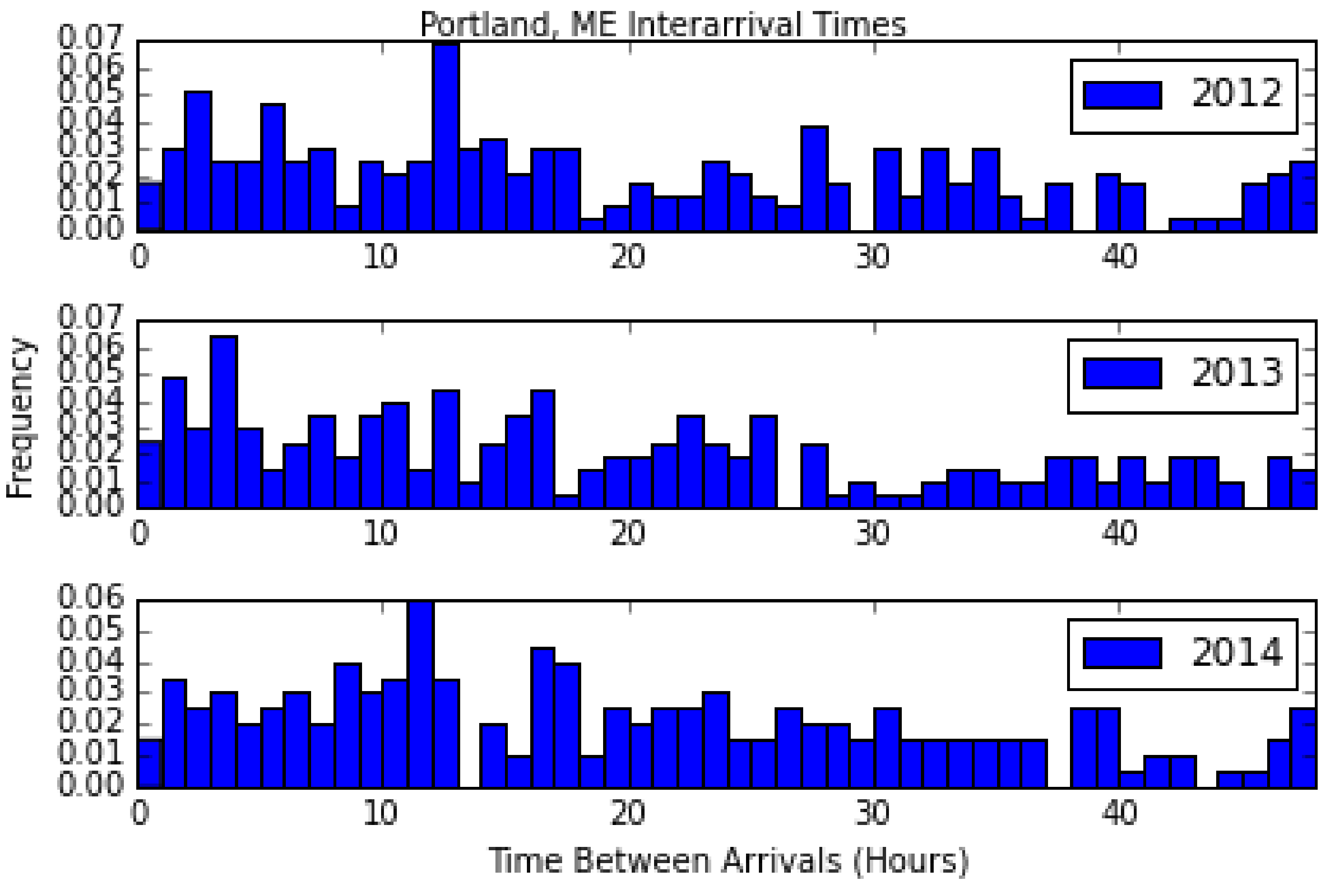
Year	Tide Range (Ft.)	Z_{25} (Ft.)	Z_{75} (Ft.)	T_{25}	T_{50}	T_{75}	TD	Arrivals
2012	13.89	1.80	8.06	0.11	0.50	0.39	0.55	287
2013	13.78	1.75	8.11	0.13	0.52	0.35	0.42	263
2014	13.86	1.71	8.16	0.14	0.59	0.27	0.21	258

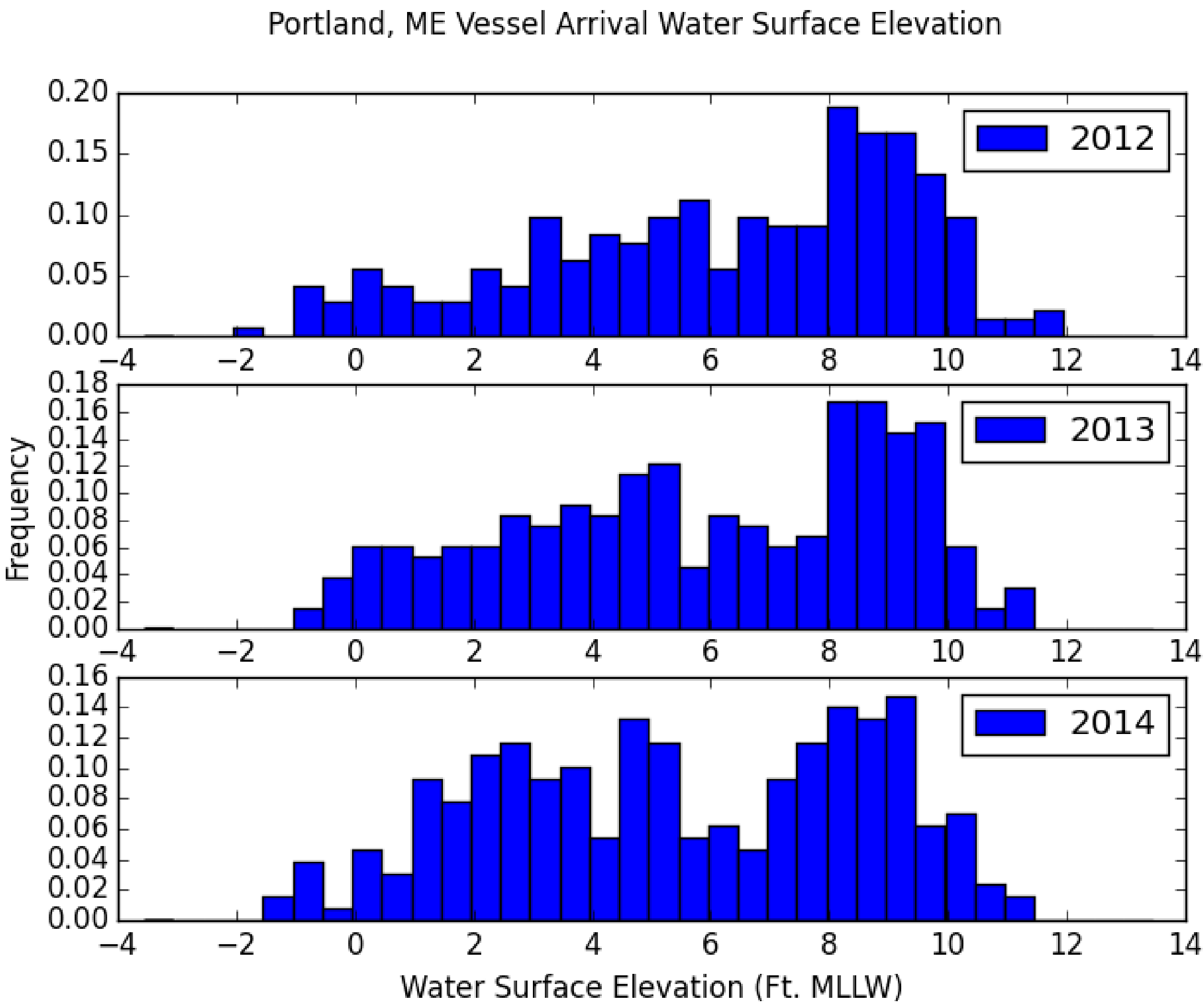



Vessel Call Frequency, Portland, ME, 2012
MON 1 0 1 0 1 4 2 2 2 3 3 2 7 2 2 0 1 4 0 4 3 2 2 3
TUE 1 0 2 1 1 1 1 1 2 0 3 0 4 2 2 5 0 3 2 2 3 4 1 0
WED 2 1 0 2 2 2 1 0 1 2 3 2 1 3 4 3 0 4 0 2 4 1 0 0
THU 4 0 1 1 1 2 1 2 1 0 1 0 2 3 2 3 2 2 0 2 2 2 4 3
FRI 3 1 6 0 1 2 0 0 1 1 2 5 1 4 3 3 4 3 1 3 3 2 1 1
SAT 2 1 0 1 1 0 0 0 0 1 1 2 2 1 1 5 2 5 1 1 3 2 2 1
SUN 2 1 0 2 1 2 3 2 1 2 0 2 1 1 0 0 0 0 2 2 1 2 1 0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)

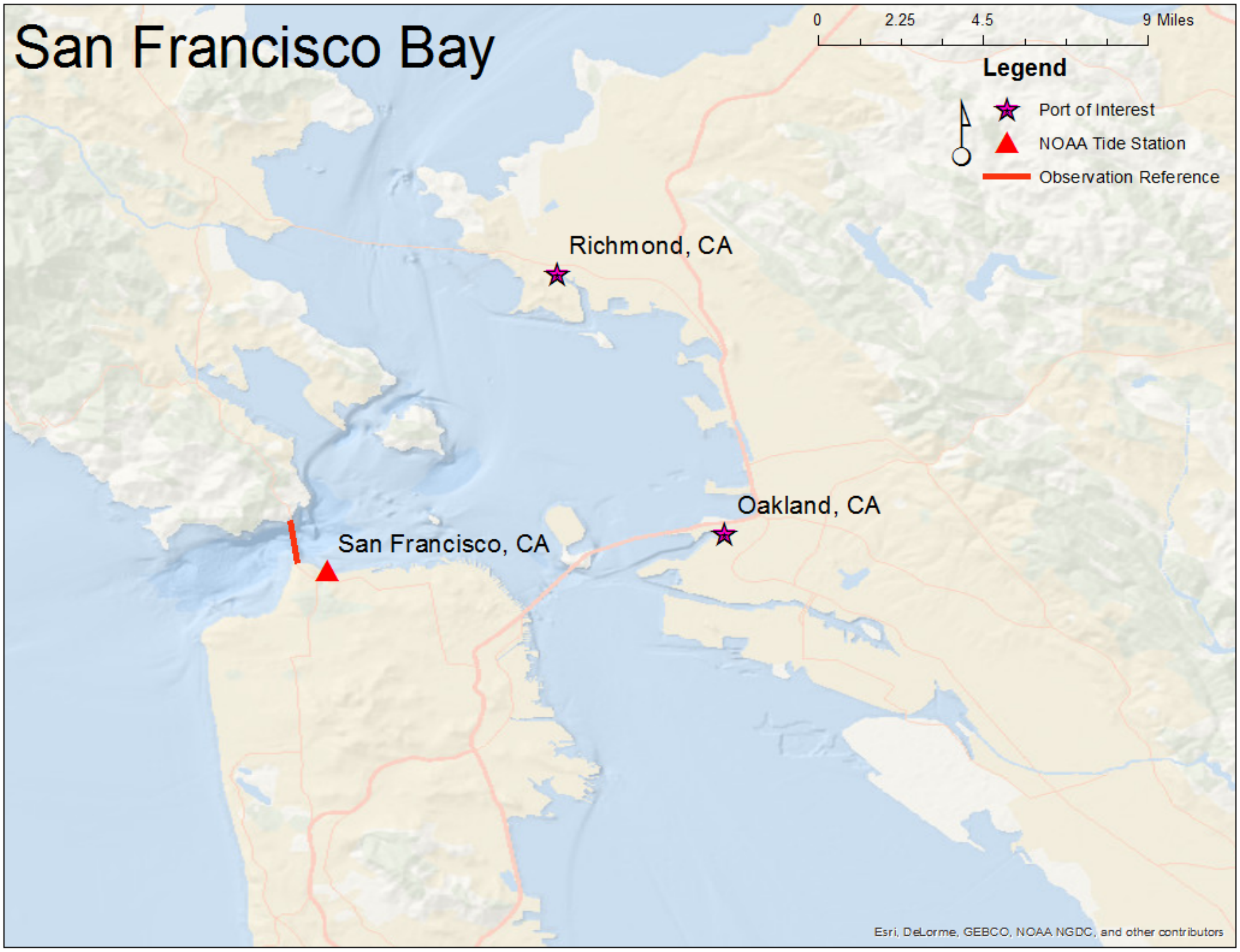

Vessel Call Frequency, Portland, ME, 2013
MON 0 3 0 3 3 0 0 2 2 1 2 1 1 3 2 4 2 2 0 0 1 0 3 2
TUE 3 1 0 1 0 2 0 2 0 0 2 3 3 5 4 2 1 3 0 0 1 1 0 0
WED 0 3 2 0 1 1 0 0 2 1 1 0 2 2 3 4 1 2 1 2 2 2 2 1
THU 1 0 1 5 1 0 2 1 2 1 3 4 3 5 1 1 2 0 4 3 2 2 1 1
FRI 2 1 0 0 1 2 0 0 1 1 1 2 2 2 9 3 0 1 2 1 0 0 1 2
SAT 1 0 2 0 0 1 3 0 0 1 1 0 2 2 1 2 2 4 3 1 0 2 3 0
SUN 1 2 1 3 1 1 2 0 5 1 5 4 1 3 0 3 0 2 2 1 2 2 1 3
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)


Vessel Call Frequency, Portland, ME, 2014
MON 2 1 0 3 2 1 0 0 2 0 3 1 2 2 2 2 2 2 1 1 4 2 0 1
TUE 1 1 0 2 2 1 4 1 0 3 2 1 2 3 2 0 2 3 0 1 2 2 2 1
WED 0 1 2 1 0 0 2 2 0 3 0 5 1 3 1 4 2 1 2 0 1 1 1 2
THU 1 2 0 3 1 1 0 1 0 2 1 6 2 2 1 1 1 4 2 1 1 2 1 1
FRI 1 2 1 1 1 1 0 0 2 1 4 2 4 3 2 2 1 3 2 2 1 1 1 2
SAT 1 2 1 3 3 2 3 0 2 1 1 1 2 1 5 0 3 2 2 3 0 1 1 2
SUN 1 1 2 0 1 1 0 1 1 2 3 3 1 0 3 2 1 1 3 1 2 0 0 0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)


Portland, ME Interarrival Times
2012
2013
2014
Frequency
Time Between Arrivals (Hours)
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0
10
20
30
40



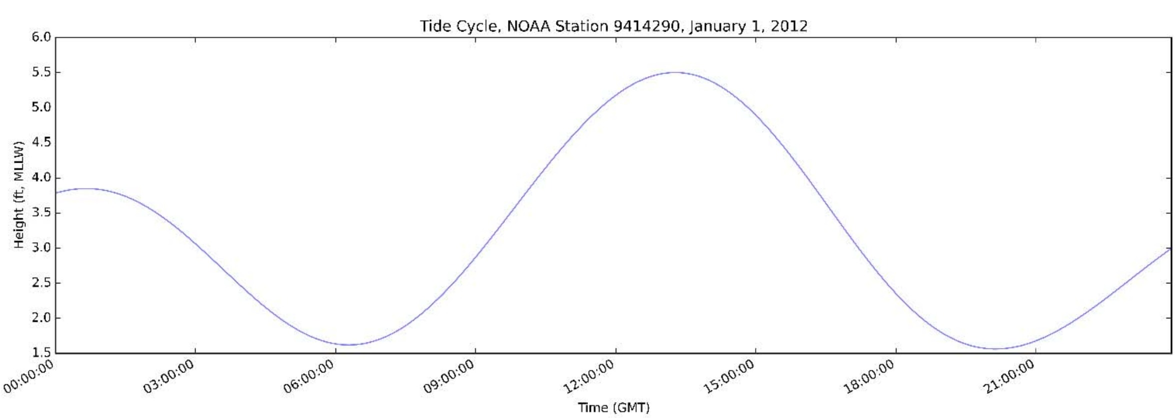
Portland, ME Vessel Arrival Water Surface Elevation
2012
2013
2014
Frequency
Water Surface Elevation (Ft. MLLW)

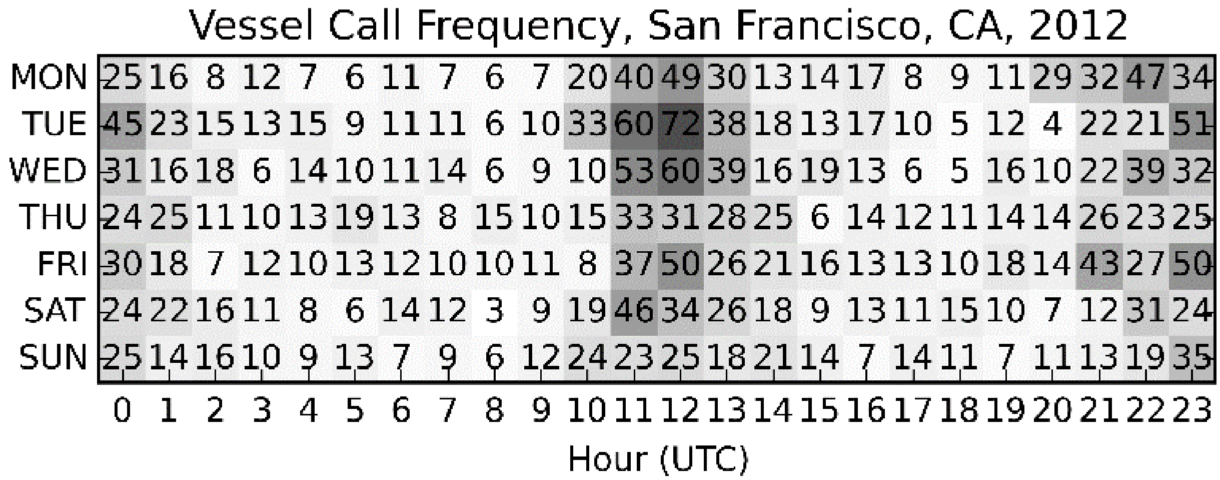


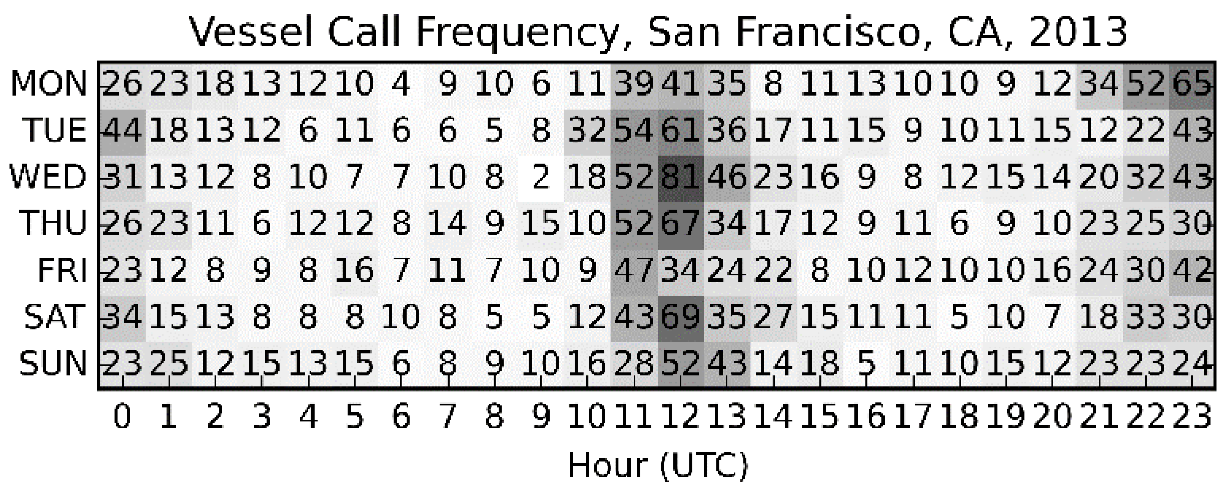
Port of Interest: **San Francisco, CA**

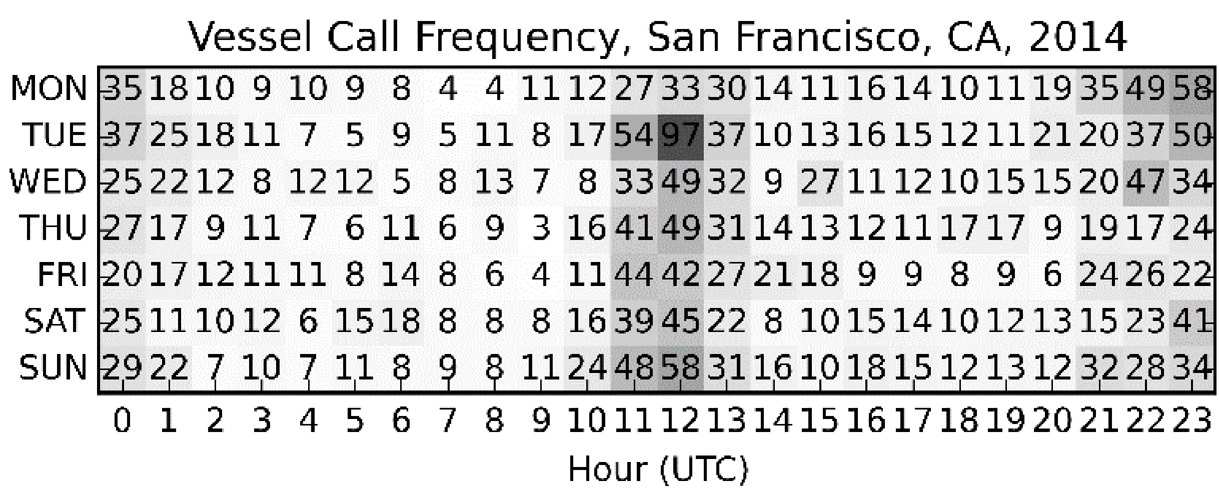
Tide Station Number: 9414290

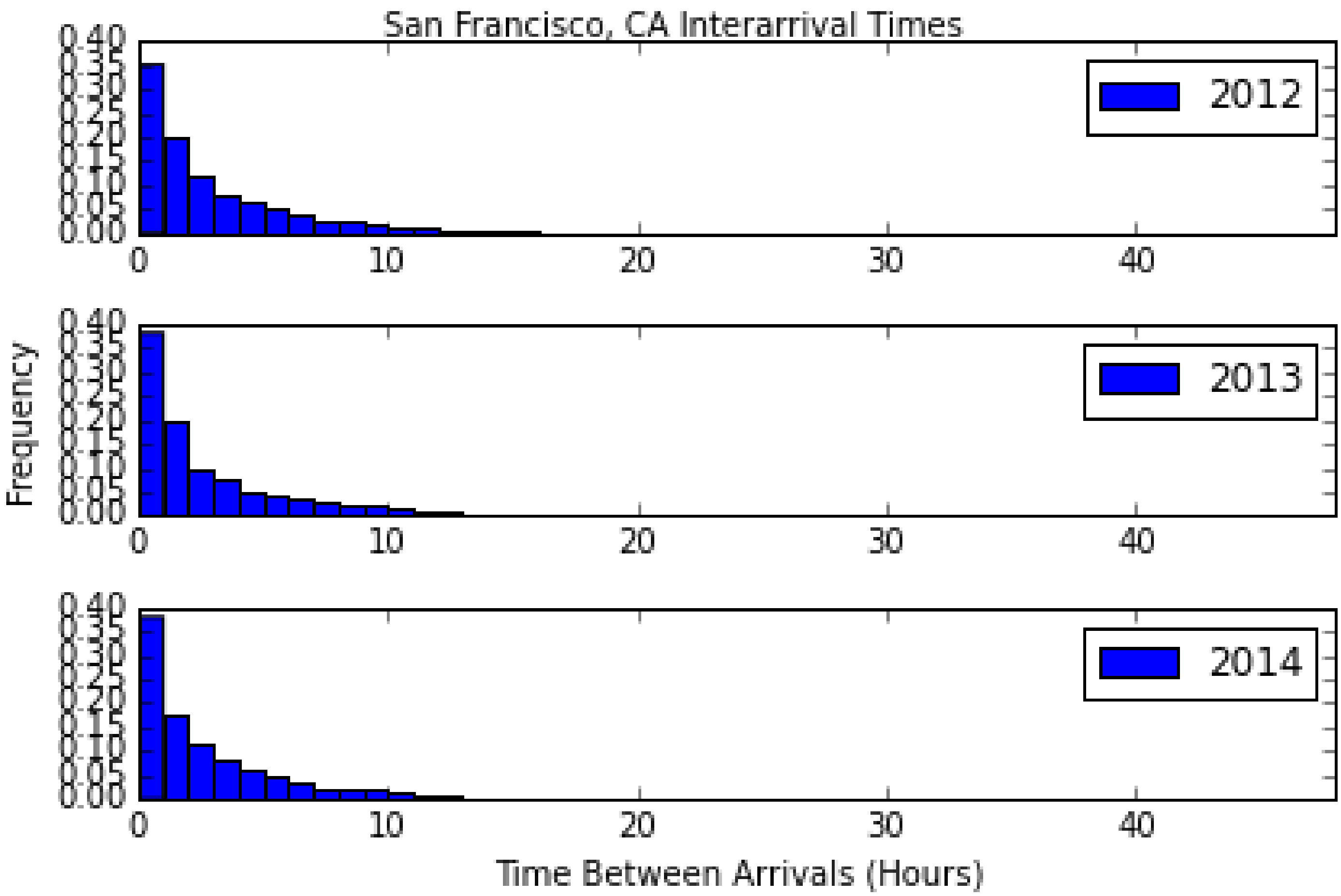
Year	Tide Range (Ft.)	Z_{25} (Ft.)	Z_{75} (Ft.)	T_{25}	T_{50}	T_{75}	TD	Arrivals
2012	9.11	1.87	4.48	0.26	0.50	0.25	-0.02	3134
2013	8.97	1.87	4.47	0.27	0.48	0.25	-0.05	3185
2014	8.75	1.87	4.49	0.27	0.48	0.25	-0.04	3109

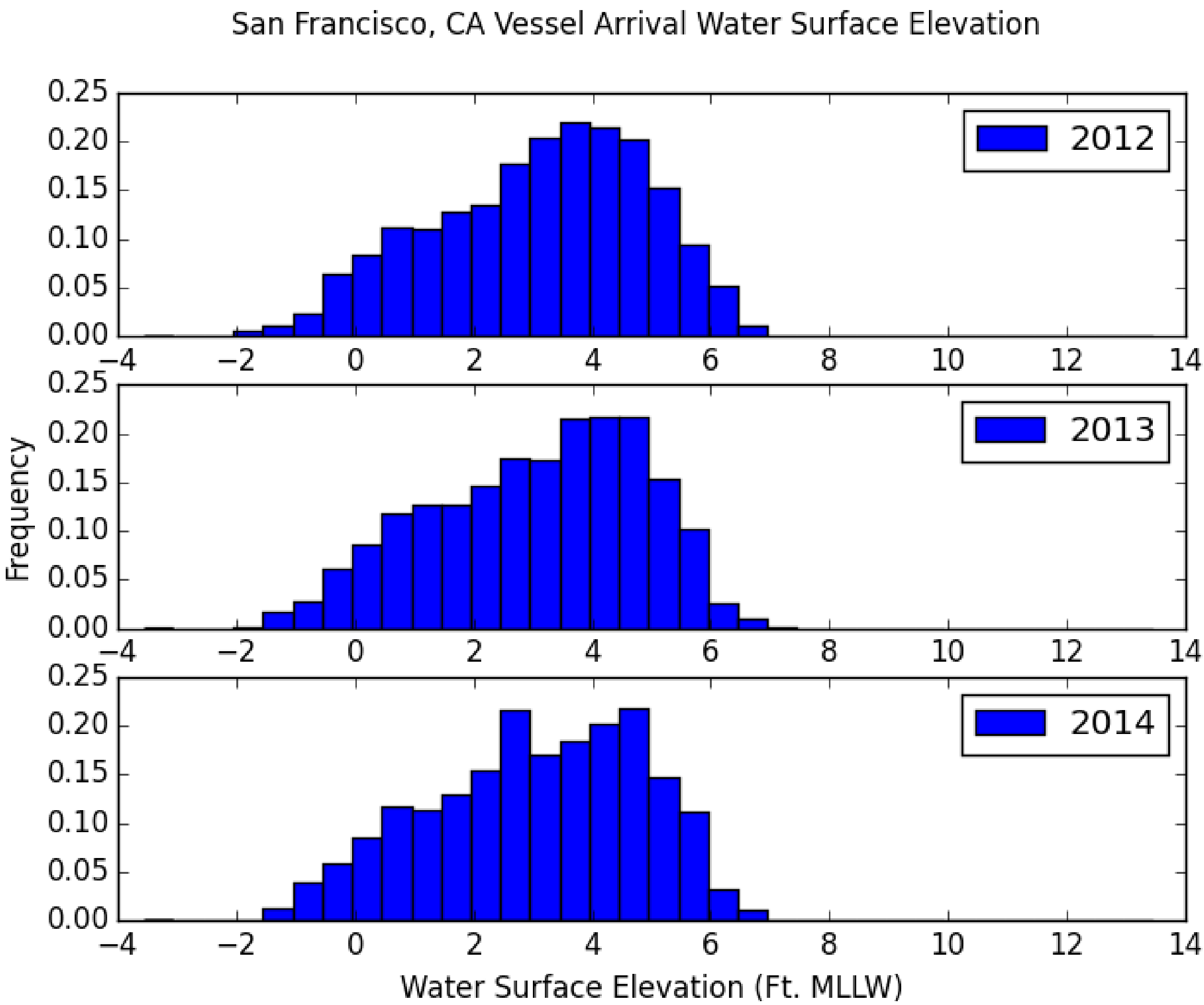


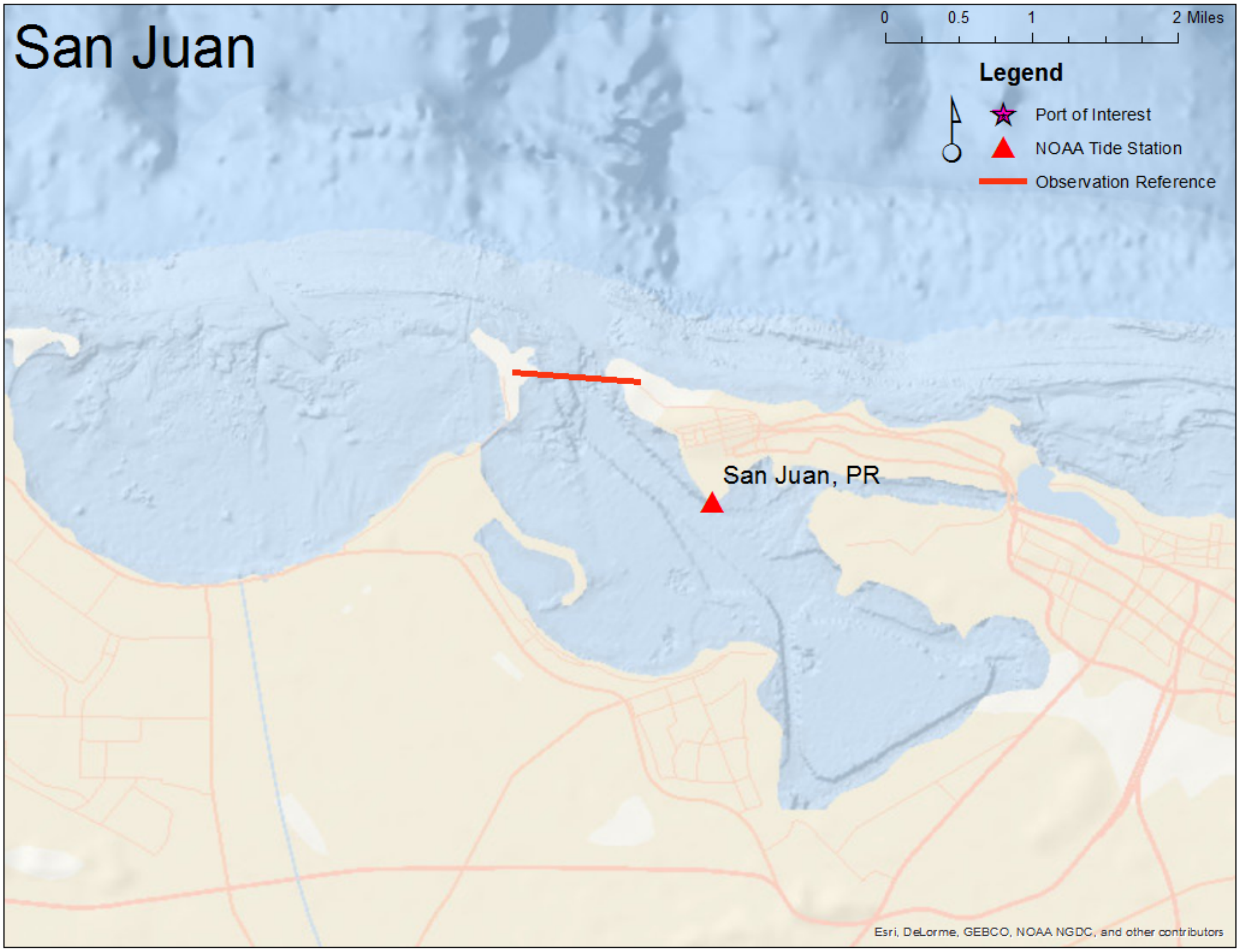

Vessel Call Frequency, San Francisco, CA, 2012
MON 25 16 8 12 7 6 11 7 6 7 20 40 49 30 13 14 17 8 9 11 29 32 47 34
TUE 45 23 15 13 15 9 11 11 6 10 33 60 72 38 18 13 17 10 5 12 4 22 21 51
WED 31 16 18 6 14 10 11 14 6 9 10 53 60 39 16 19 13 6 5 16 10 22 39 32
THU 24 25 11 10 13 19 13 8 15 10 15 33 31 28 25 6 14 12 11 14 14 26 23 25
FRI 30 18 7 12 10 13 12 10 10 11 8 37 50 26 21 16 13 13 10 18 14 43 27 50
SAT 24 22 16 11 8 6 14 12 3 9 19 46 34 26 18 9 13 11 15 10 7 12 31 24
SUN 25 14 16 10 9 13 7 9 6 12 24 23 25 18 21 14 7 14 11 7 11 13 19 35
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)


Vessel Call Frequency, San Francisco, CA, 2013
MON 26 23 18 13 12 10 4 9 10 6 11 39 41 35 8 11 13 10 10 9 12 34 52 65
TUE 44 18 13 12 6 11 6 6 5 8 32 54 61 36 17 11 15 9 10 11 15 12 22 43
WED 31 13 12 8 10 7 7 10 8 2 18 52 81 46 23 16 9 8 12 15 14 20 32 43
THU 26 23 11 6 12 12 8 14 9 15 10 52 67 34 17 12 9 11 6 9 10 23 25 30
FRI 23 12 8 9 8 16 7 11 7 10 9 47 34 24 22 8 10 12 10 10 16 24 30 42
SAT 34 15 13 8 8 8 10 8 5 5 12 43 69 35 27 15 11 11 5 10 7 18 33 30
SUN 23 25 12 15 13 15 6 8 9 10 16 28 52 43 14 18 5 11 10 15 12 23 23 24
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)


Vessel Call Frequency, San Francisco, CA, 2014
MON 35 18 10 9 10 9 8 4 4 11 12 27 33 30 14 11 16 14 10 11 19 35 49 58
TUE 37 25 18 11 7 5 9 5 11 8 17 54 97 37 10 13 16 15 12 11 21 20 37 50
WED 25 22 12 8 12 12 5 8 13 7 8 33 49 32 9 27 11 12 10 15 15 20 47 34
THU 27 17 9 11 7 6 11 6 9 3 16 41 49 31 14 13 12 11 17 17 9 19 17 24
FRI 20 17 12 11 11 8 14 8 6 4 11 44 42 27 21 18 9 9 8 9 6 24 26 22
SAT 25 11 10 12 6 15 18 8 8 8 16 39 45 22 8 10 15 14 10 12 13 15 23 41
SUN 29 22 7 10 7 11 8 9 8 11 24 48 58 31 16 10 18 15 12 13 12 32 28 34
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)


San Francisco, CA Interarrival Times
2012
2013
2014
Frequency
Time Between Arrivals (Hours)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
10
20
30
40

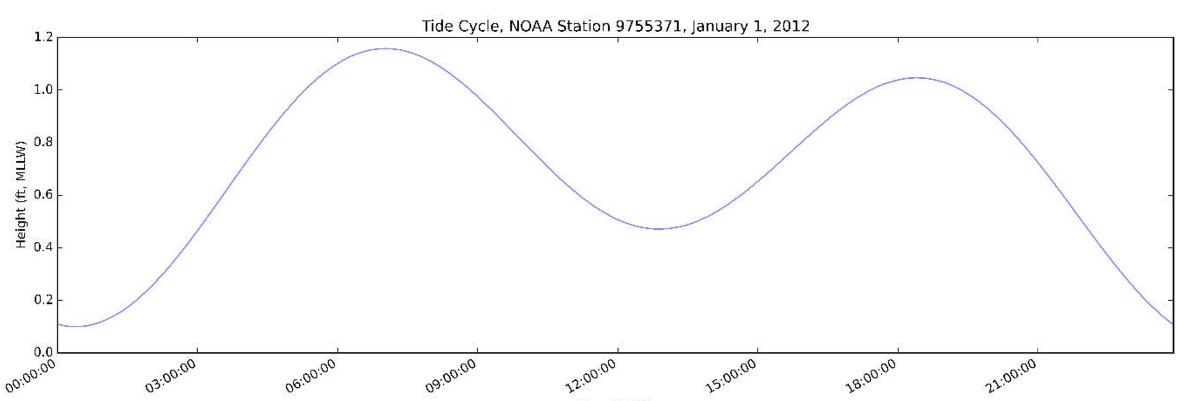

San Francisco, CA Vessel Arrival Water Surface Elevation
Frequency
2012
2013
2014
Water Surface Elevation (Ft. MLLW)

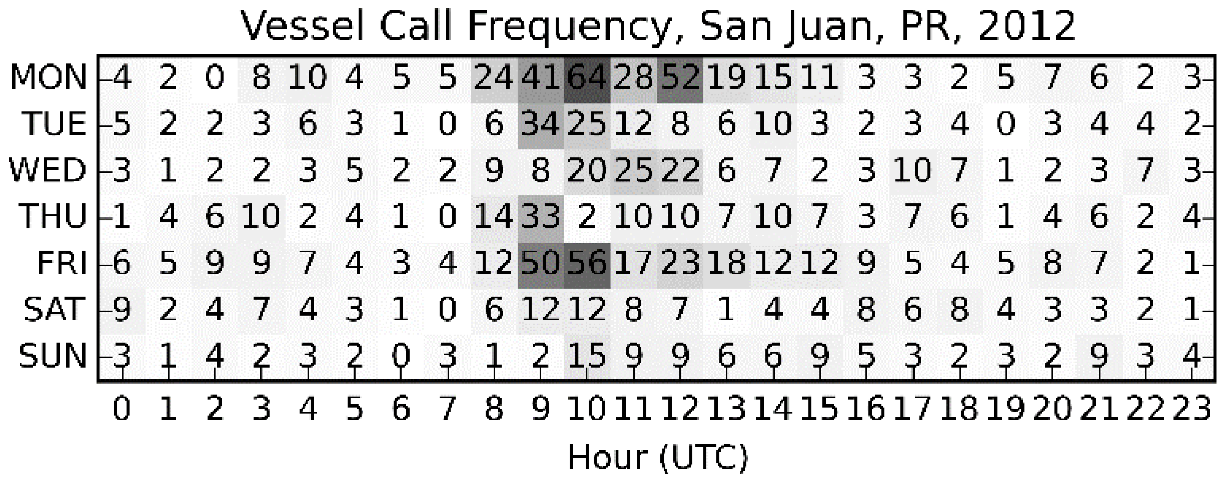


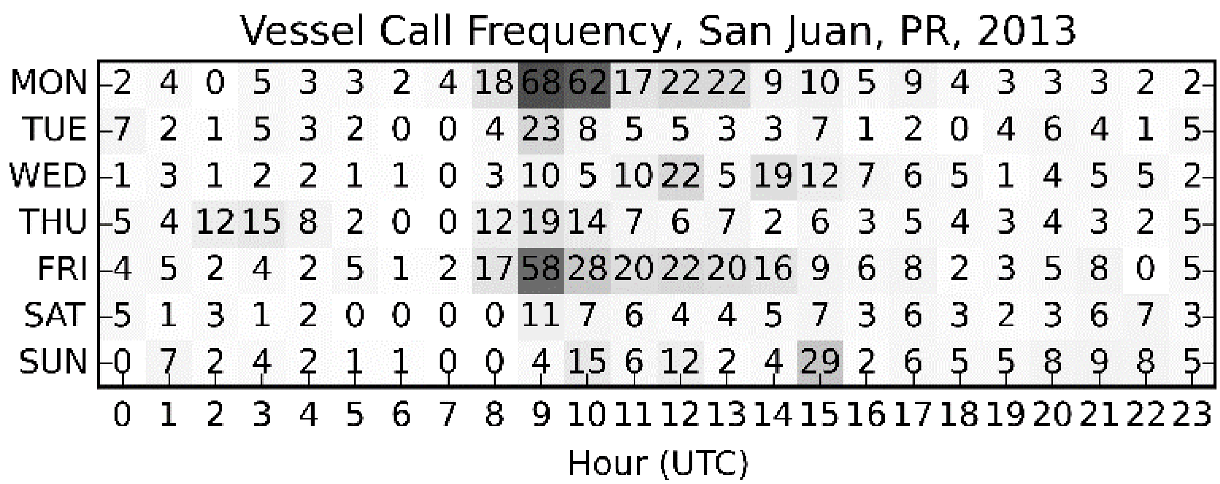
Port of Interest: **San Juan, PR**

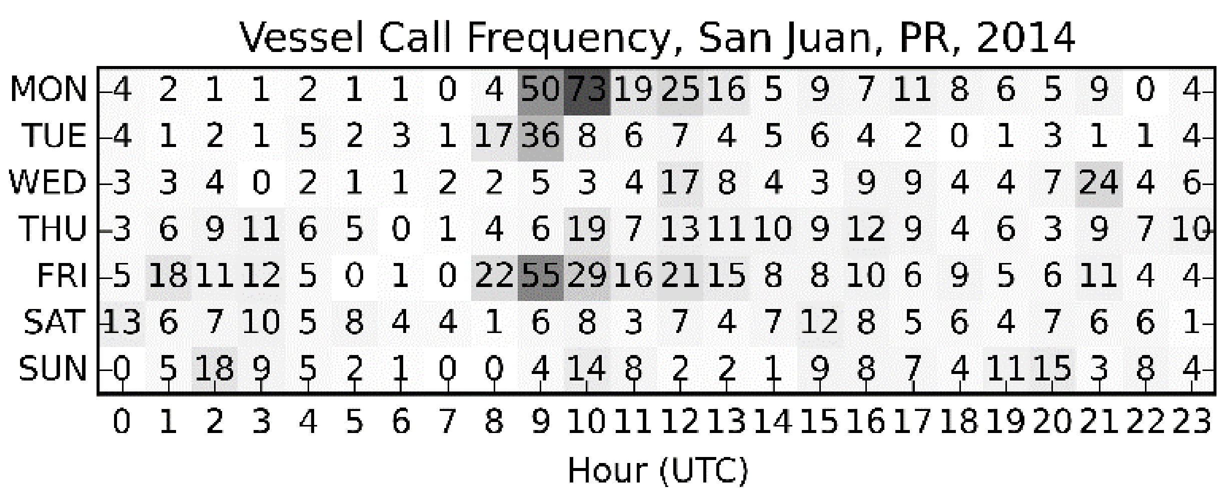
Tide Station Number: 9755371

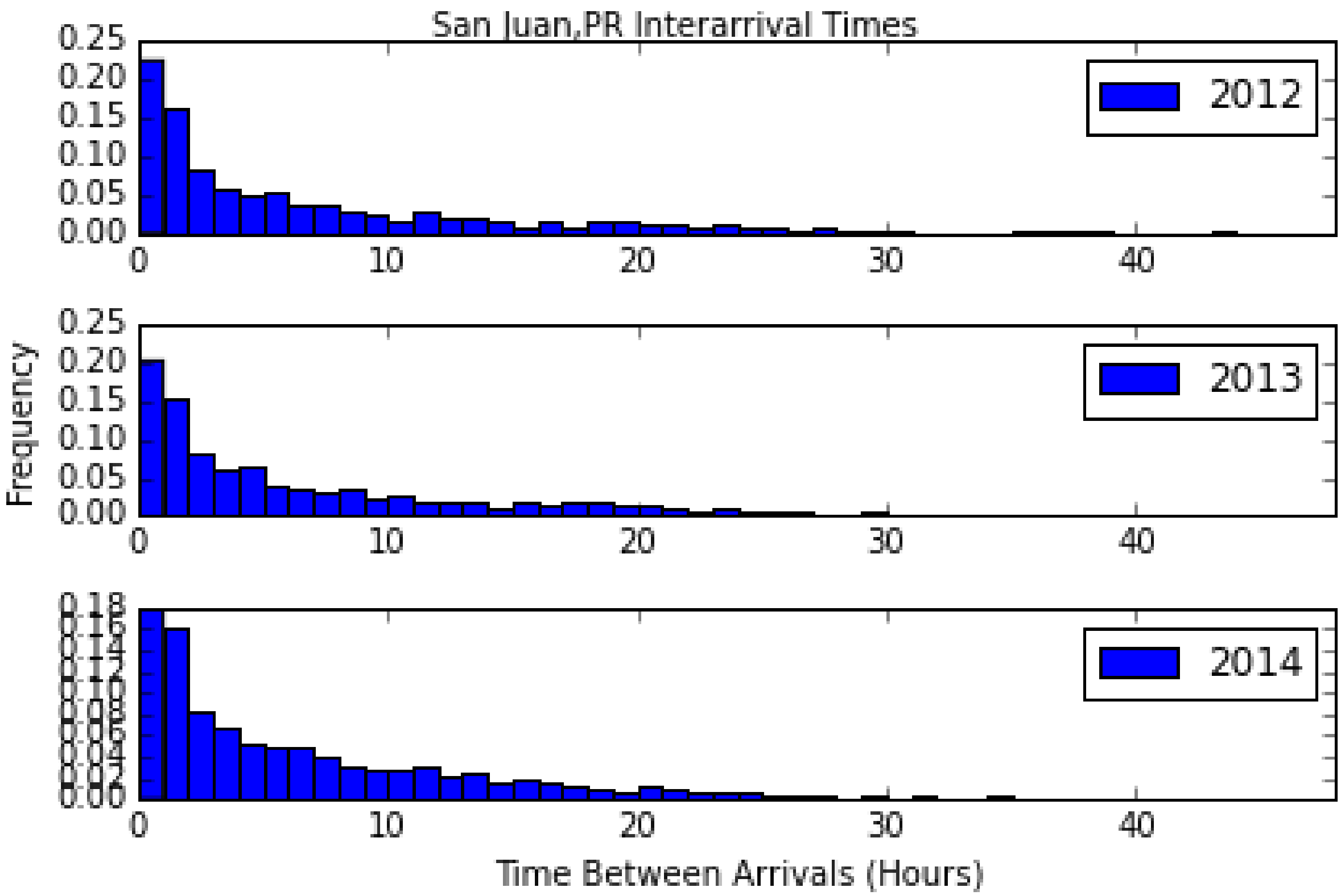
Year	Tide Range (Ft.)	Z_{25} (Ft.)	Z_{75} (Ft.)	T_{25}	T_{50}	T_{75}	TD	Arrivals
2012	2.71	0.41	1.12	0.26	0.50	0.25	-0.02	1293
2013	2.62	0.41	1.12	0.26	0.50	0.24	-0.05	1141
2014	2.53	0.41	1.12	0.26	0.52	0.23	-0.05	1265



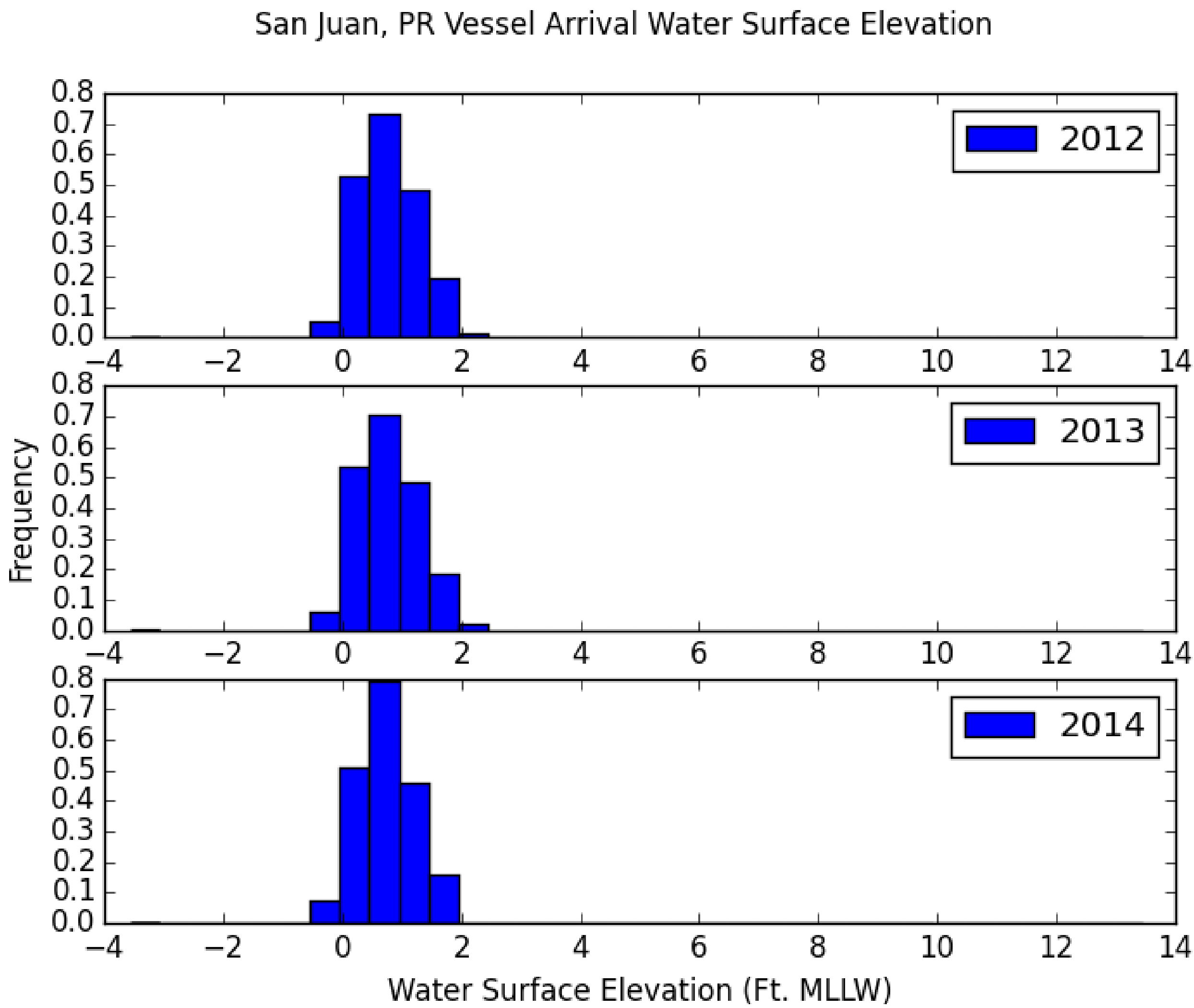

Vessel Call Frequency, San Juan, PR, 2012
MON 4 2 0 8 10 4 5 5 24 41 64 28 52 19 15 11 3 3 2 5 7 6 2 3
TUE 5 2 2 3 6 3 1 0 6 34 25 12 8 6 10 3 2 3 4 0 3 4 4 2
WED 3 1 2 2 3 5 2 2 9 8 20 25 22 6 7 2 3 10 7 1 2 3 7 3
THU 1 4 6 10 2 4 1 0 14 33 2 10 10 7 10 7 3 7 6 1 4 6 2 4
FRI 6 5 9 9 7 4 3 4 12 50 56 17 23 18 12 12 9 5 4 5 8 7 2 1
SAT 9 2 4 7 4 3 1 0 6 12 12 8 7 1 4 4 8 6 8 4 3 3 2 1
SUN 3 1 4 2 3 2 0 3 1 2 15 9 9 6 6 9 5 3 2 3 2 9 3 4
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)

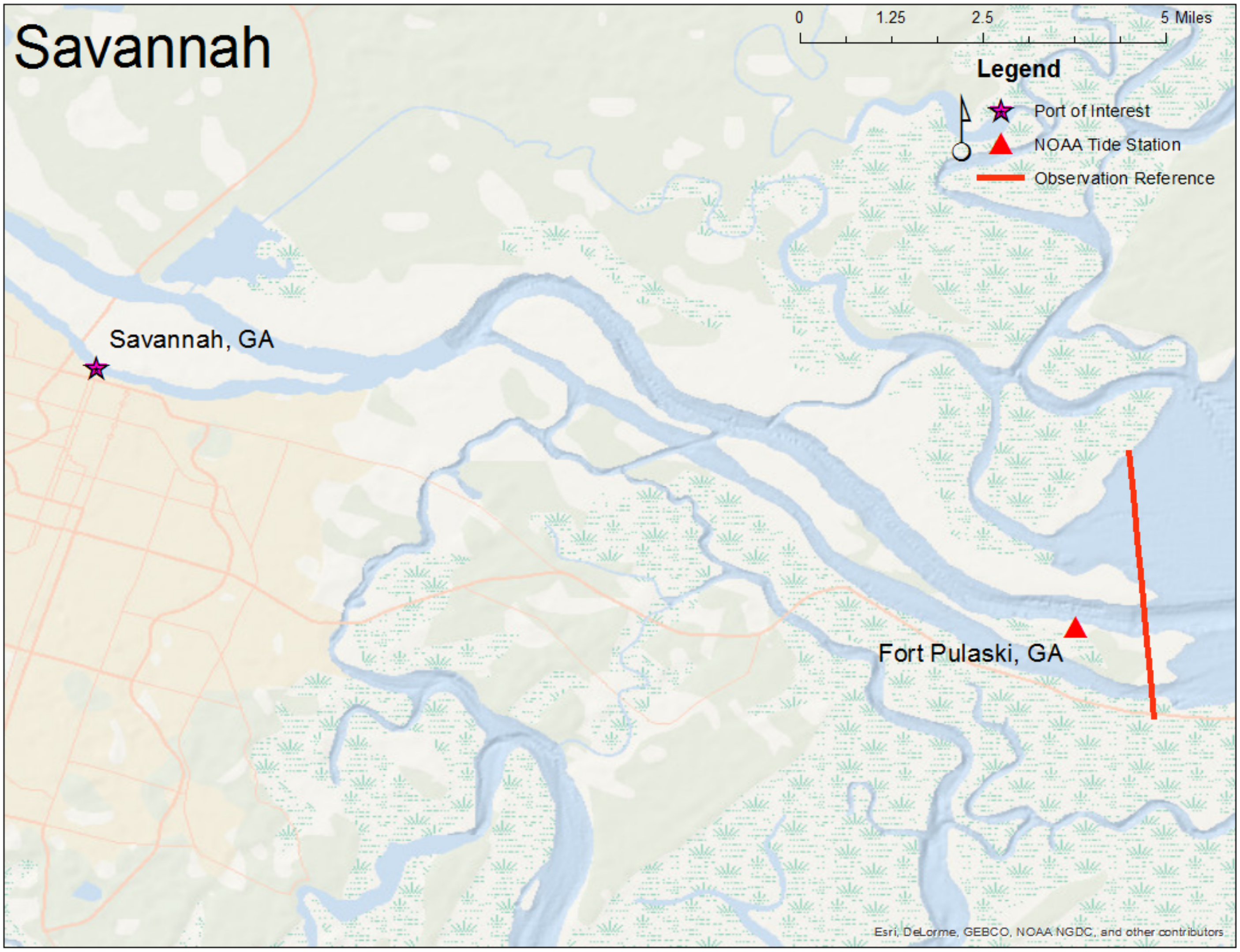

Vessel Call Frequency, San Juan, PR, 2013
MON 2 4 0 5 3 3 2 4 18 68 62 17 22 22 9 10 5 9 4 3 3 3 2 2
TUE 7 2 1 5 3 2 0 0 4 23 8 5 5 3 3 7 1 2 0 4 6 4 1 5
WED 1 3 1 2 2 1 1 0 3 10 5 10 22 5 19 12 7 6 5 1 4 5 5 2
THU 5 4 12 15 8 2 0 0 12 19 14 7 6 7 2 6 3 5 4 3 4 3 2 5
FRI 4 5 2 4 2 5 1 2 17 58 28 20 22 20 16 9 6 8 2 3 5 8 0 5
SAT 5 1 3 1 2 0 0 0 0 11 7 6 4 4 5 7 3 6 3 2 3 6 7 3
SUN 0 7 2 4 2 1 1 0 0 4 15 6 12 2 4 29 2 6 5 5 8 9 8 5
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)


Vessel Call Frequency, San Juan, PR, 2014
MON 4 2 1 1 2 1 1 0 4 50 73 19 25 16 5 9 7 11 8 6 5 9 0 4
TUE 4 1 2 1 5 2 3 1 17 36 8 6 7 4 5 6 4 2 0 1 3 1 1 4
WED 3 3 4 0 2 1 1 2 2 5 3 4 17 8 4 3 9 9 4 4 7 24 4 6
THU 3 6 9 11 6 5 0 1 4 6 19 7 13 11 10 9 12 9 4 6 3 9 7 10
FRI 5 18 11 12 5 0 1 0 22 55 29 16 21 15 8 8 10 6 9 5 6 11 4 4
SAT 13 6 7 10 5 8 4 4 1 6 8 3 7 4 7 12 8 5 6 4 7 6 6 1
SUN 0 5 18 9 5 2 1 0 0 4 14 8 2 2 1 9 8 7 4 11 15 3 8 4
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)



San Juan,PR Interarrival Times
2012
2013
2014
Frequency
0.25
0.20
0.15
0.10
0.05
0.00
0.18
0
10
20
30
40
Time Between Arrivals (Hours)

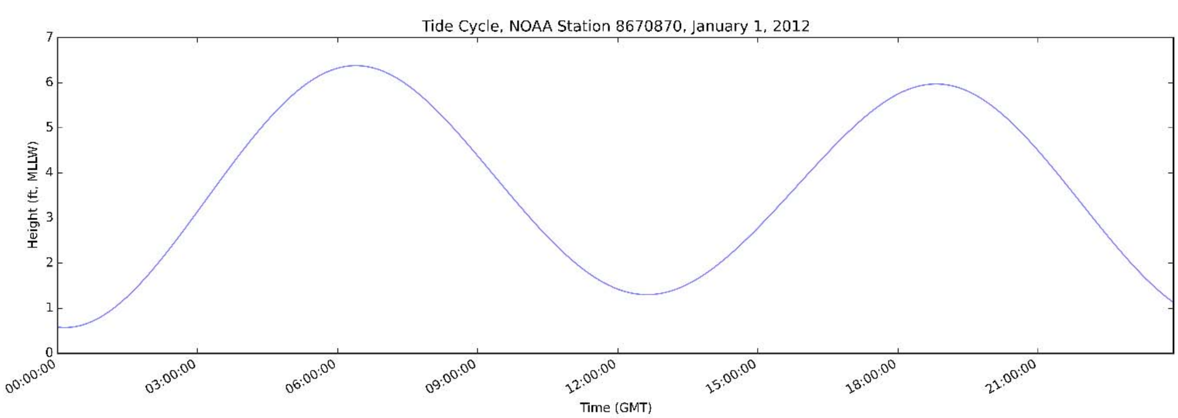

San Juan, PR Vessel Arrival Water Surface Elevation
Frequency
2012
2013
2014
Water Surface Elevation (Ft. MLLW)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
−4
−2
0
2
4
6
8
10
12
14

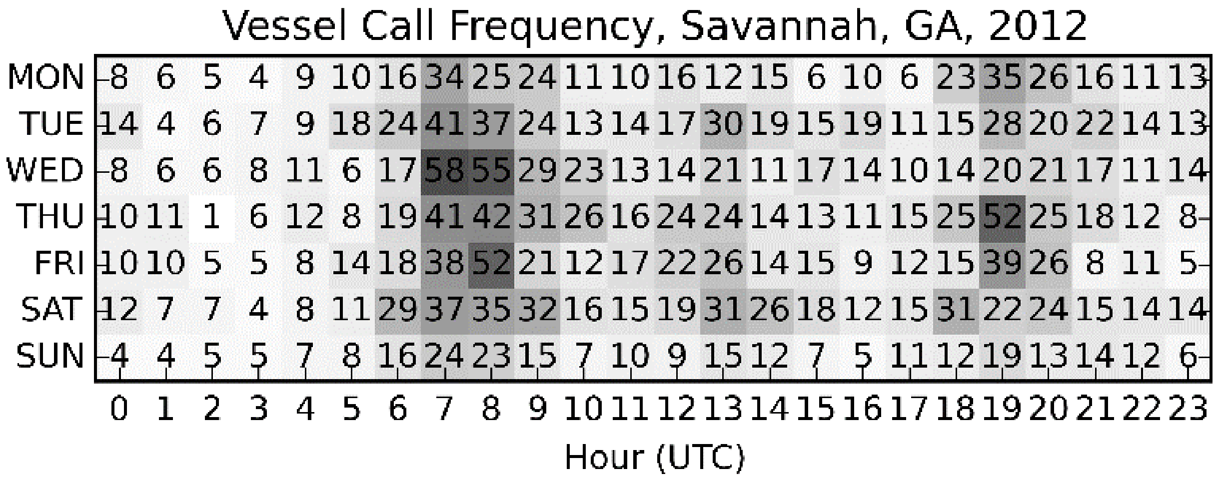


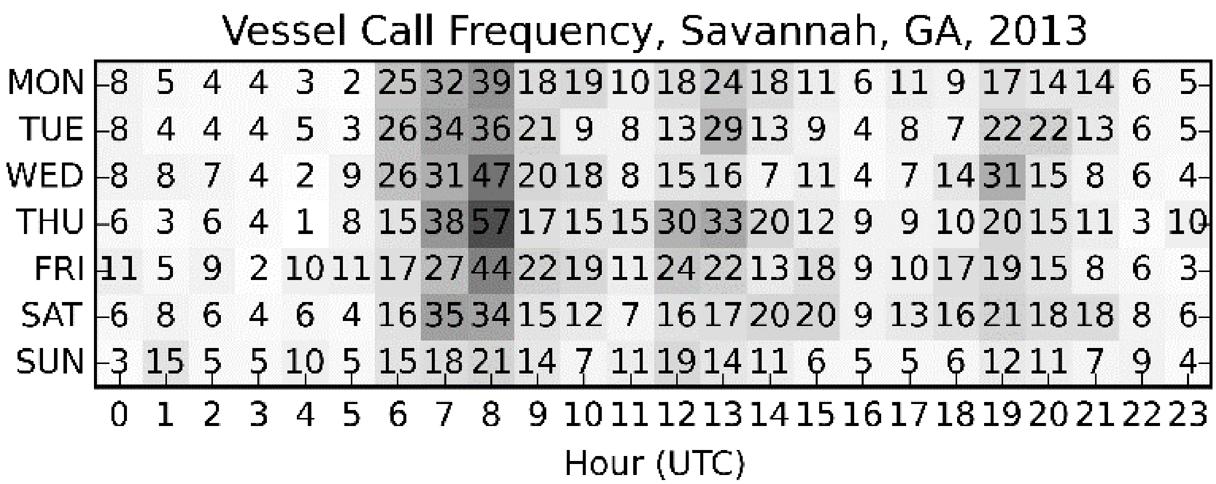
Port of Interest: **Savannah, GA**

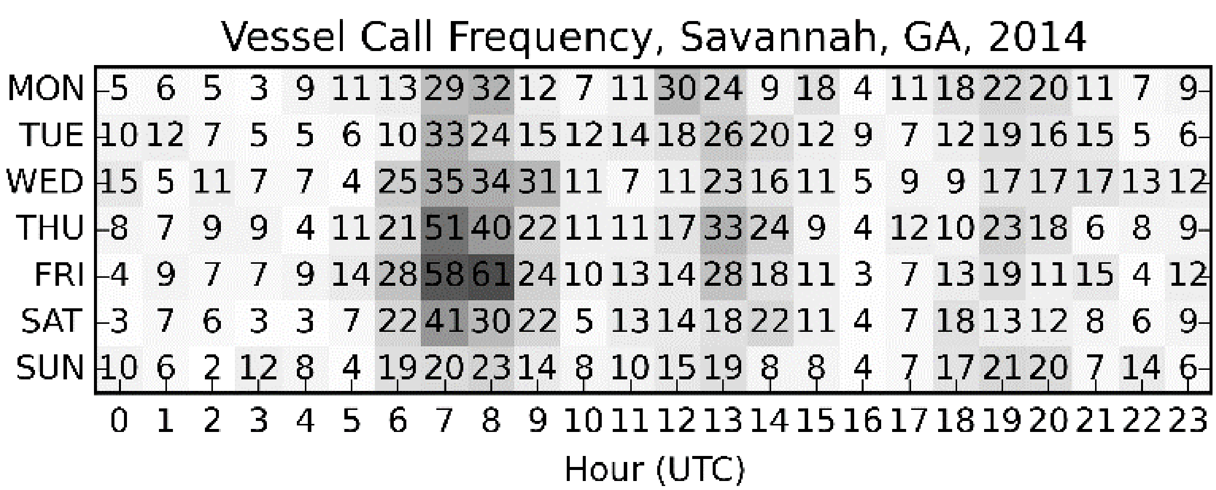
Tide Station Number: 8670870

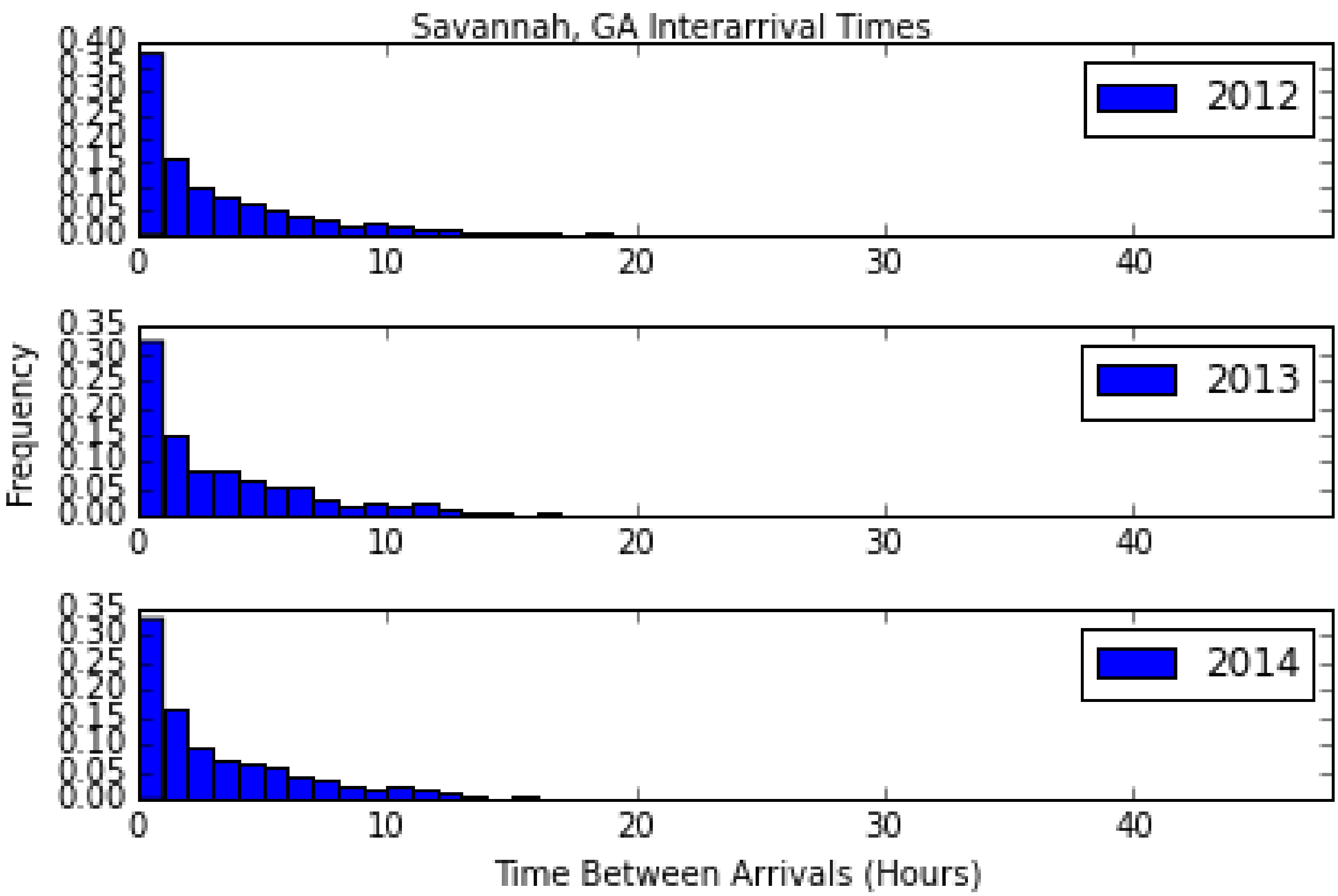
Year	Tide Range (Ft.)	Z_{25} (Ft.)	Z_{75} (Ft.)	T_{25}	T_{50}	T_{75}	TD	Arrivals
2012	10.40	1.51	6.09	0.24	0.52	0.24	0.00	2802
2013	10.29	1.50	6.13	0.23	0.50	0.27	0.07	2253
2014	10.75	1.48	6.15	0.22	0.51	0.27	0.11	2358



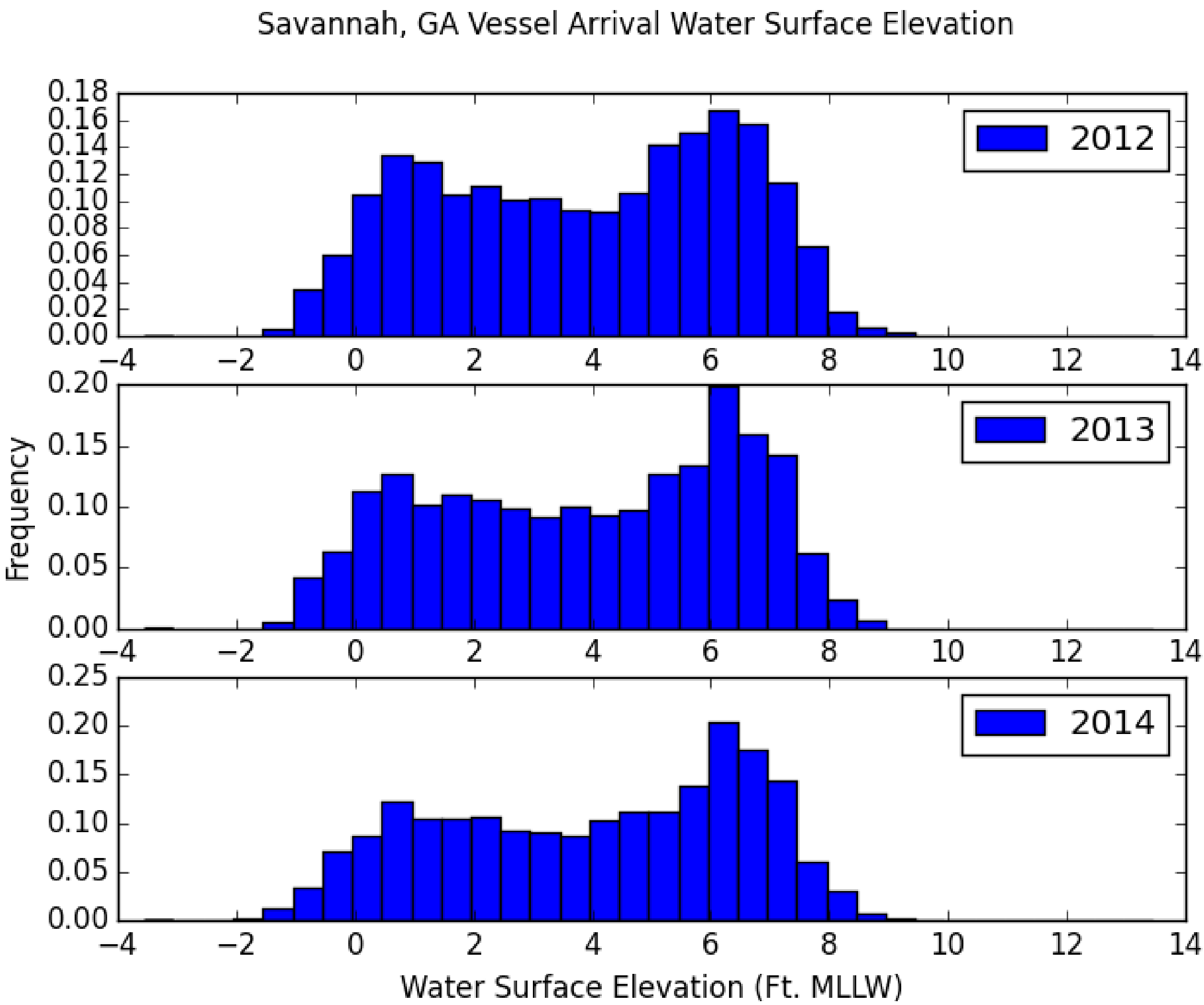

Vessel Call Frequency, Savannah, GA, 2012
MON 8 6 5 4 9 10 16 34 25 24 11 10 16 12 15 6 10 6 23 35 26 16 11 13
TUE 14 4 6 7 9 18 24 41 37 24 13 14 17 30 19 15 19 11 15 28 20 22 14 13
WED 8 6 6 8 11 6 17 58 55 29 23 13 14 21 11 17 14 10 14 20 21 17 11 14
THU 10 11 1 6 12 8 19 41 42 31 26 16 24 24 14 13 11 15 25 52 25 18 12 8
FRI 10 10 5 5 8 14 18 38 52 21 12 17 22 26 14 15 9 12 15 39 26 8 11 5
SAT 12 7 7 4 8 11 29 37 35 32 16 15 19 31 26 18 12 15 31 22 24 15 14 14
SUN 4 4 5 5 7 8 16 24 23 15 7 10 9 15 12 7 5 11 12 19 13 14 12 6
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)


Vessel Call Frequency, Savannah, GA, 2013
MON 8 5 4 4 3 2 25 32 39 18 19 10 18 24 18 11 6 11 9 17 14 14 6 5
TUE 8 4 4 4 5 3 26 34 36 21 9 8 13 29 13 9 4 8 7 22 22 13 6 5
WED 8 8 7 4 2 9 26 31 47 20 18 8 15 16 7 11 4 7 14 31 15 8 6 4
THU 6 3 6 4 1 8 15 38 57 17 15 15 30 33 20 12 9 9 10 20 15 11 3 10
FRI 11 5 9 2 10 11 17 27 44 22 19 11 24 22 13 18 9 10 17 19 15 8 6 3
SAT 6 8 6 4 6 4 16 35 34 15 12 7 16 17 20 20 9 13 16 21 18 18 8 6
SUN 3 15 5 5 10 5 15 18 21 14 7 11 19 14 11 6 5 5 6 12 11 7 9 4
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)

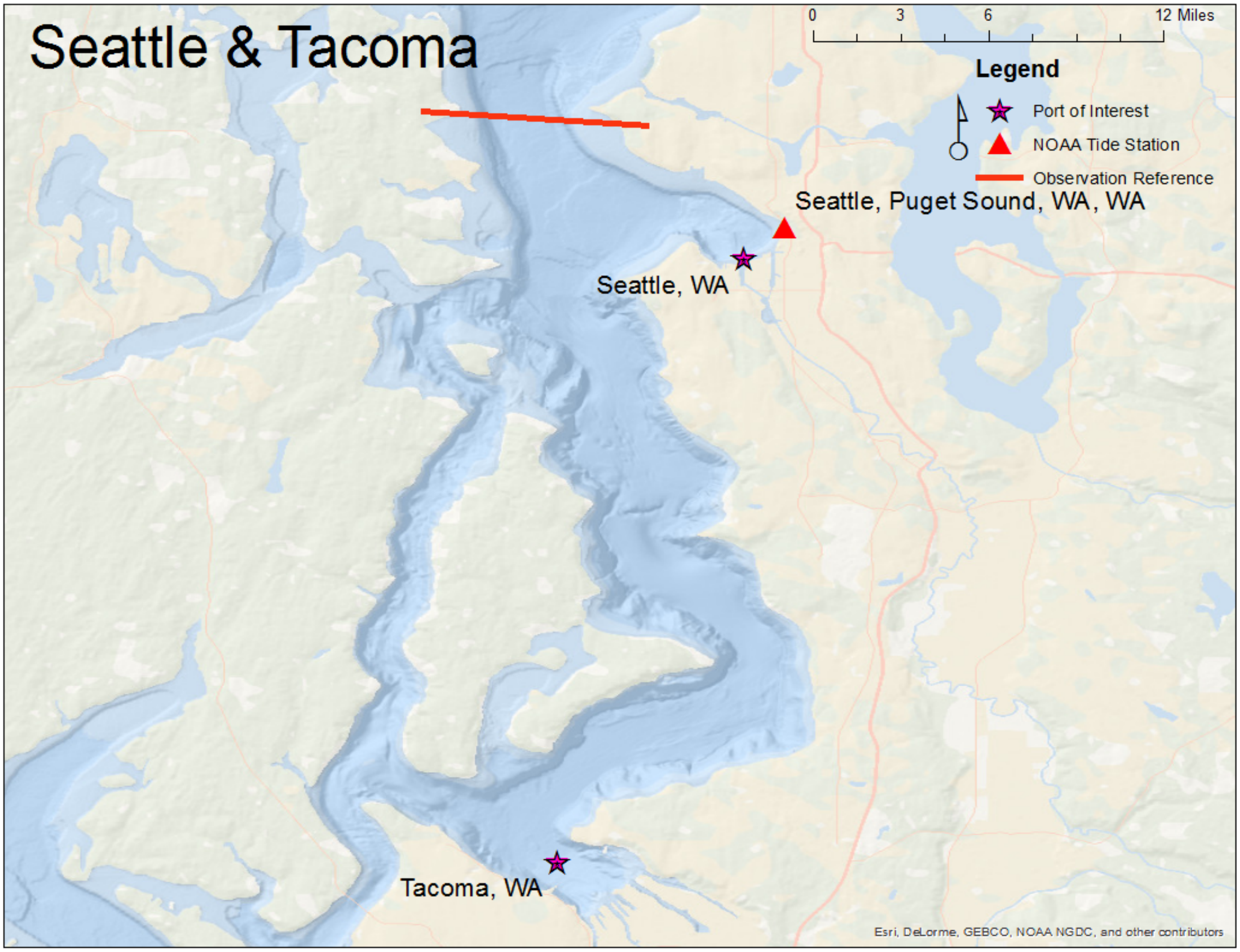

Vessel Call Frequency, Savannah, GA, 2014
MON 5 6 5 3 9 11 13 29 32 12 7 11 30 24 9 18 4 11 18 22 20 11 7 9
TUE 10 12 7 5 5 6 10 33 24 15 12 14 18 26 20 12 9 7 12 19 16 15 5 6
WED 15 5 11 7 7 4 25 35 34 31 11 7 11 23 16 11 5 9 9 17 17 17 13 12
THU 8 7 9 9 4 11 21 51 40 22 11 11 17 33 24 9 4 12 10 23 18 6 8 9
FRI 4 9 7 7 9 14 28 58 61 24 10 13 14 28 18 11 3 7 13 19 11 15 4 12
SAT 3 7 6 3 3 7 22 41 30 22 5 13 14 18 22 11 4 7 18 13 12 8 6 9
SUN 10 6 2 12 8 4 19 20 23 14 8 10 15 19 8 8 4 7 17 21 20 7 14 6
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)



Savannah, GA Interarrival Times
2012
2013
2014
Frequency
Time Between Arrivals (Hours)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
10
20
30
40



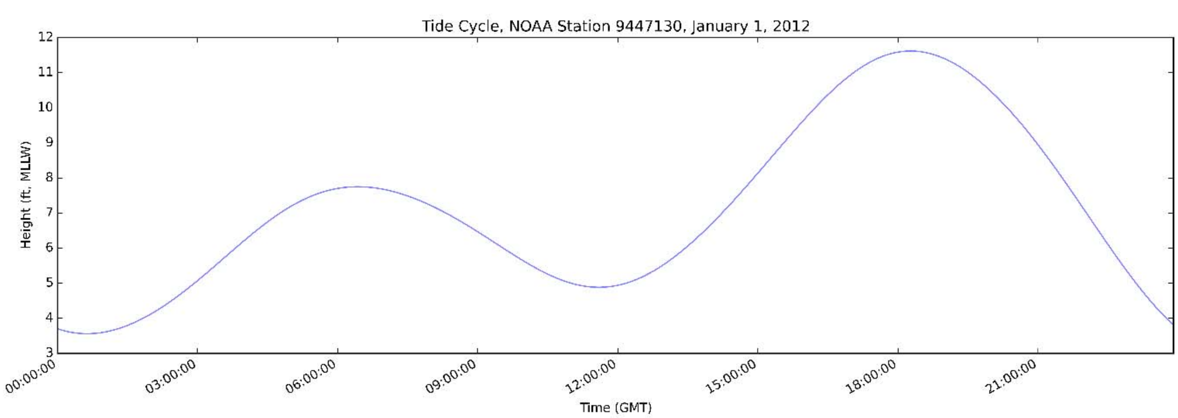
Savannah, GA Vessel Arrival Water Surface Elevation
Frequency
2012
2013
2014
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
0.05
0.15
0.25
−4
−2
0
2
4
6
8
10
12
14
Water Surface Elevation (Ft. MLLW)

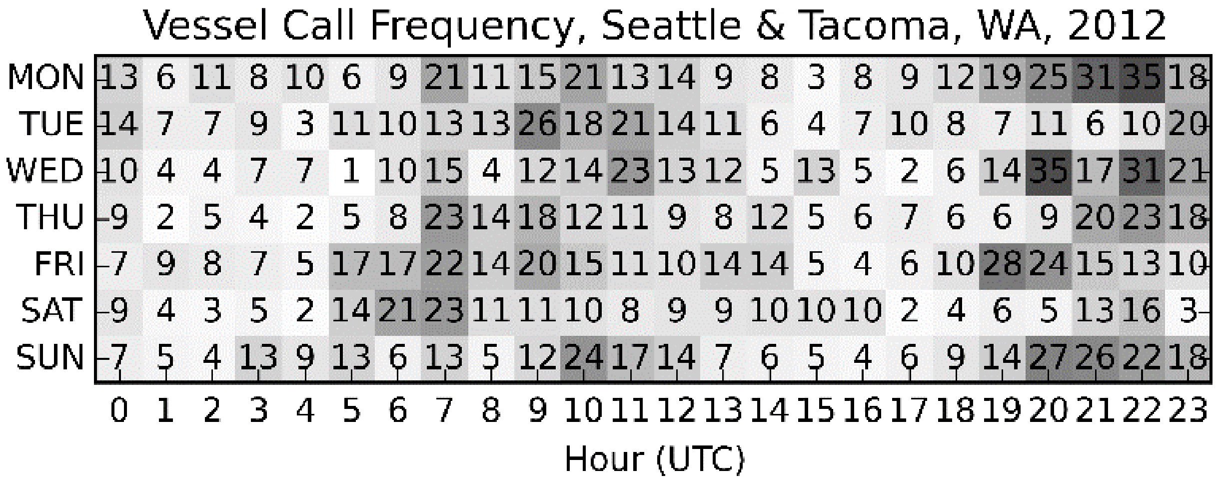


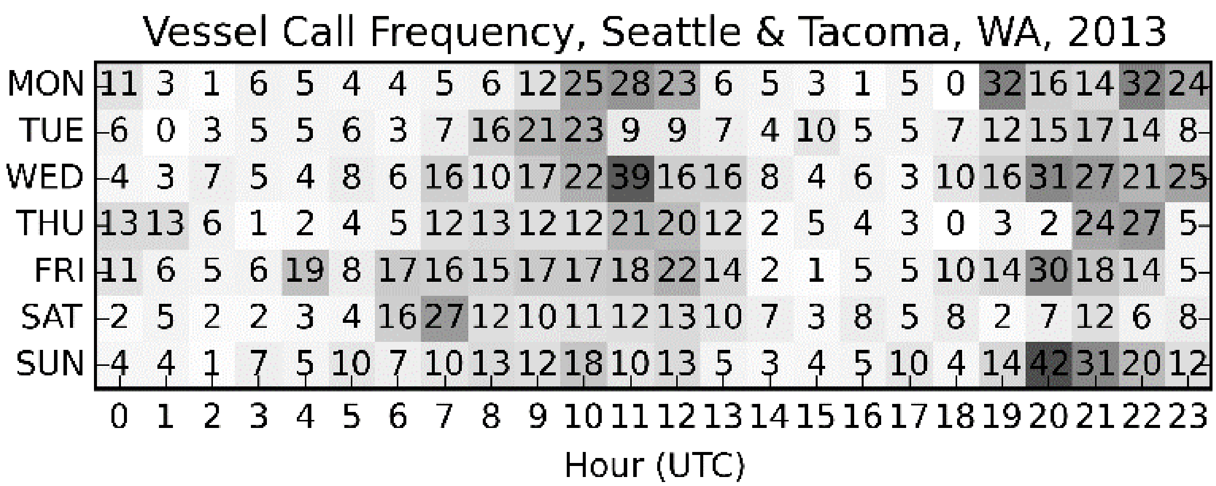
Port of Interest: **Seattle & Tacoma, WA**

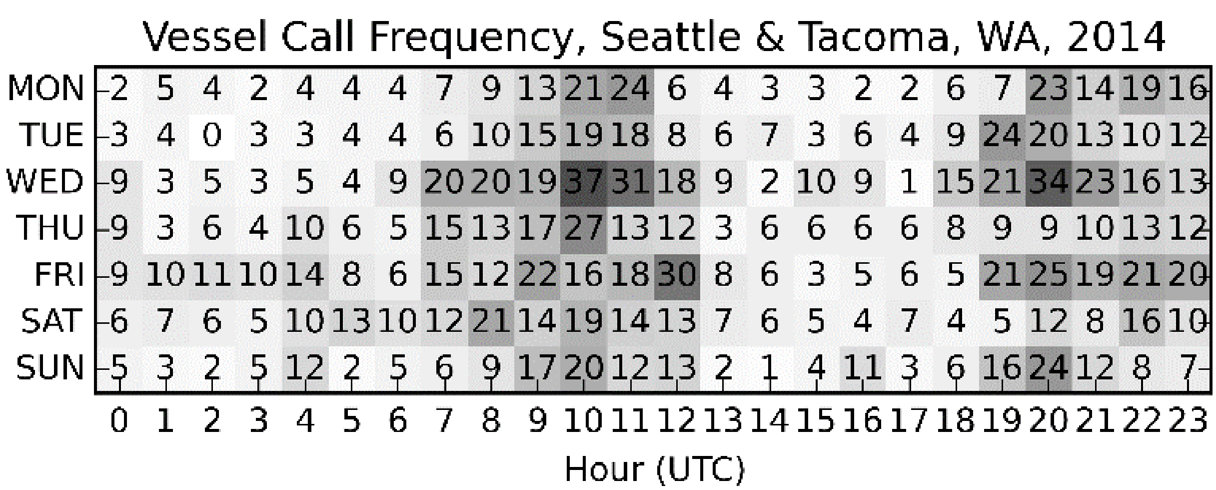
Tide Station Number: 9447130

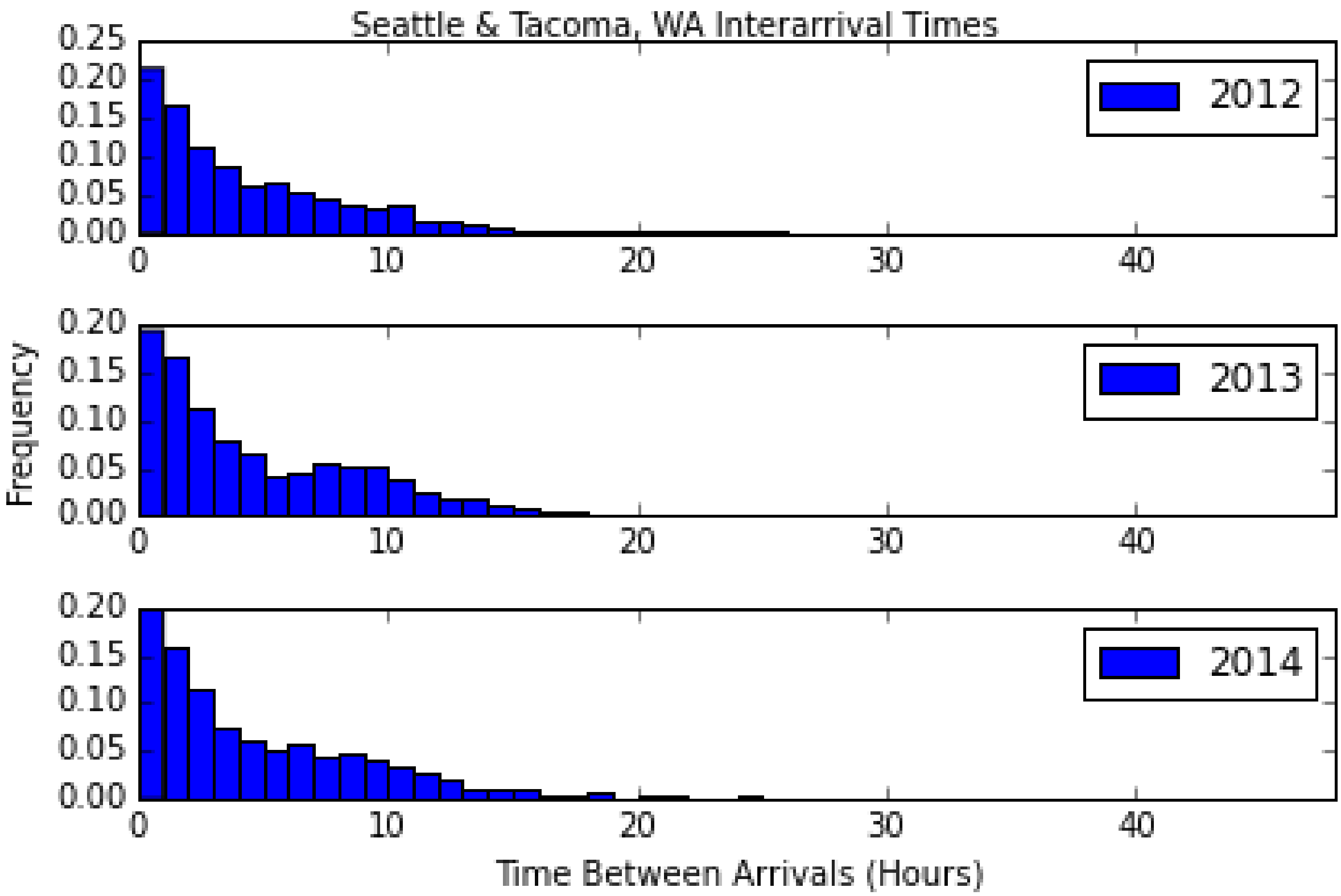
Year	Tide Range (Ft.)	Z_{25} (Ft.)	Z_{75} (Ft.)	T_{25}	T_{50}	T_{75}	TD	Arrivals
2012	16.80	4.27	9.37	0.25	0.49	0.26	0.00	1937
2013	16.76	4.31	9.36	0.26	0.50	0.25	-0.03	1787
2014	16.58	4.33	9.36	0.26	0.50	0.24	-0.03	1738

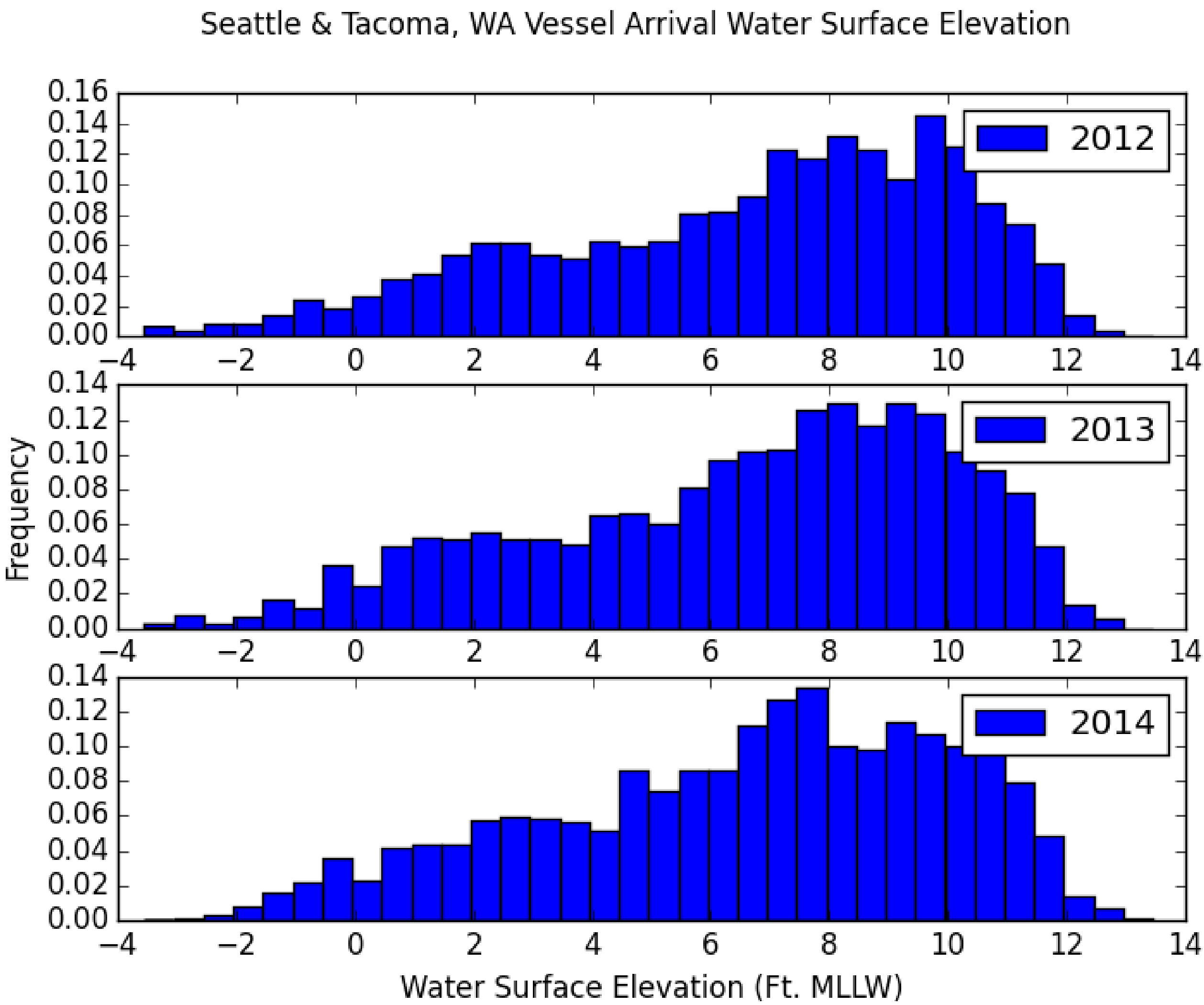


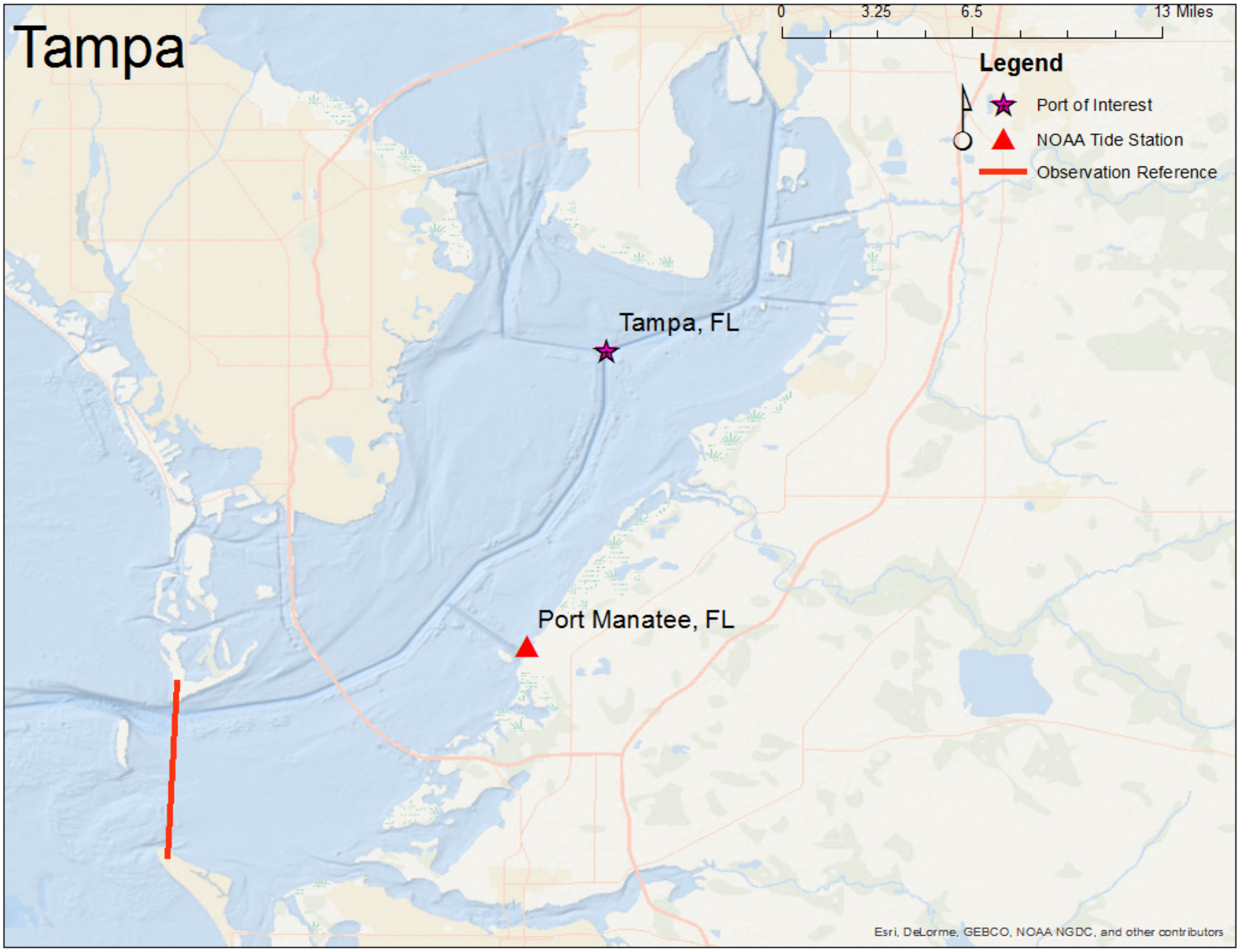

Vessel Call Frequency, Seattle & Tacoma, WA, 2012
MON 13 6 11 8 10 6 9 21 11 15 21 13 14 9 8 3 8 9 12 19 25 31 35 18
TUE 14 7 7 9 3 11 10 13 13 26 18 21 14 11 6 4 7 10 8 7 11 6 10 20
WED 10 4 4 7 7 1 10 15 4 12 14 23 13 12 5 13 5 2 6 14 35 17 31 21
THU 9 2 5 4 2 5 8 23 14 18 12 11 9 8 12 5 6 7 6 6 9 20 23 18
FRI 7 9 8 7 5 17 17 22 14 20 15 11 10 14 14 5 4 6 10 28 24 15 13 10
SAT 9 4 3 5 2 14 21 23 11 11 10 8 9 9 10 10 10 2 4 6 5 13 16 3
SUN 7 5 4 13 9 13 6 13 5 12 24 17 14 7 6 5 4 6 9 14 27 26 22 18
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)


Vessel Call Frequency, Seattle & Tacoma, WA, 2013
MON 11 3 1 6 5 4 4 5 6 12 25 28 23 6 5 3 1 5 0 32 16 14 32 24
TUE 6 0 3 5 5 6 3 7 16 21 23 9 9 7 4 10 5 5 7 12 15 17 14 8
WED 4 3 7 5 4 8 6 16 10 17 22 39 16 16 8 4 6 3 10 16 31 27 21 25
THU 13 13 6 1 2 4 5 12 13 12 12 21 20 12 2 5 4 3 0 3 2 24 27 5
FRI 11 6 5 6 19 8 17 16 15 17 17 18 22 14 2 1 5 5 10 14 30 18 14 5
SAT 2 5 2 2 3 4 16 27 12 10 11 12 13 10 7 3 8 5 8 2 7 12 6 8
SUN 4 4 1 7 5 10 7 10 13 12 18 10 13 5 3 4 5 10 4 14 42 31 20 12
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)


Vessel Call Frequency, Seattle & Tacoma, WA, 2014
MON 2 5 4 2 4 4 4 7 9 13 21 24 6 4 3 3 2 2 6 7 23 14 19 16
TUE 3 4 0 3 3 4 4 6 10 15 19 18 8 6 7 3 6 4 9 24 20 13 10 12
WED 9 3 5 3 5 4 9 20 20 19 37 31 18 9 2 10 9 1 15 21 34 23 16 13
THU 9 3 6 4 10 6 5 15 13 17 27 13 12 3 6 6 6 6 8 9 9 10 13 12
FRI 9 10 11 10 14 8 6 15 12 22 16 18 30 8 6 3 5 6 5 21 25 19 21 20
SAT 6 7 6 5 10 13 10 12 21 14 19 14 13 7 6 5 4 7 4 5 12 8 16 10
SUN 5 3 2 5 12 2 5 6 9 17 20 12 13 2 1 4 11 3 6 16 24 12 8 7
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)


Seattle & Tacoma, WA Interarrival Times
0.25
0.20
0.15
0.10
0.05
0.00
0
10
20
30
40
2012
Frequency
0.20
0.15
0.10
0.05
0.00
2013
0.20
0.15
0.10
0.05
0.00
2014
Time Between Arrivals (Hours)

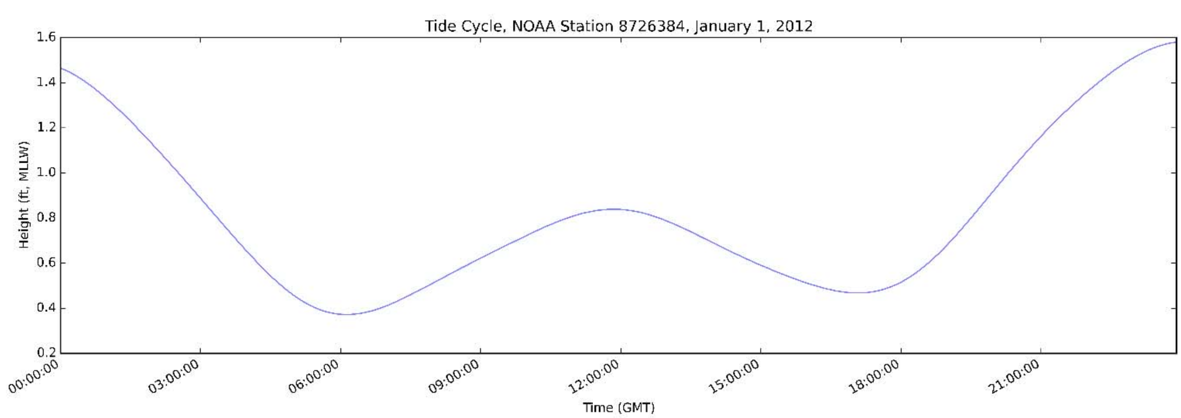

Seattle & Tacoma, WA Vessel Arrival Water Surface Elevation
2012
2013
2014
Frequency
Water Surface Elevation (Ft. MLLW)
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
−4
−2
0
2
4
6
8
10
12
14

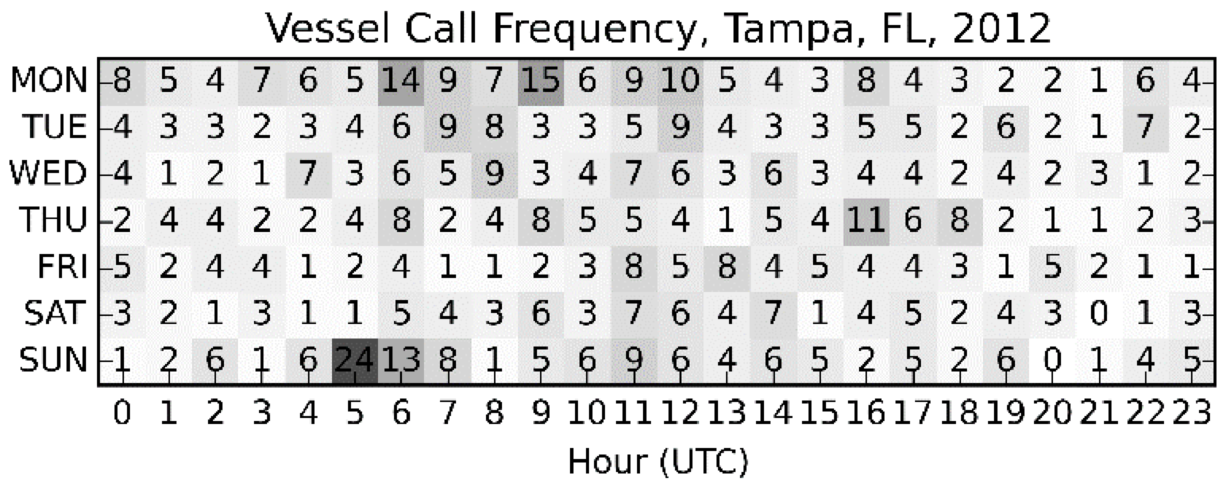


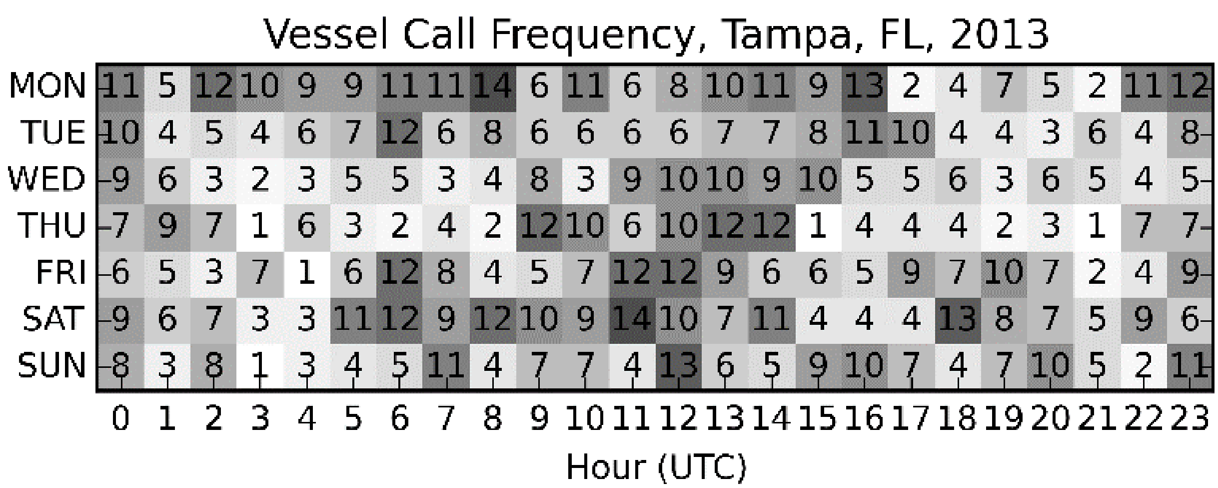
Port of Interest: **Tampa, FL**

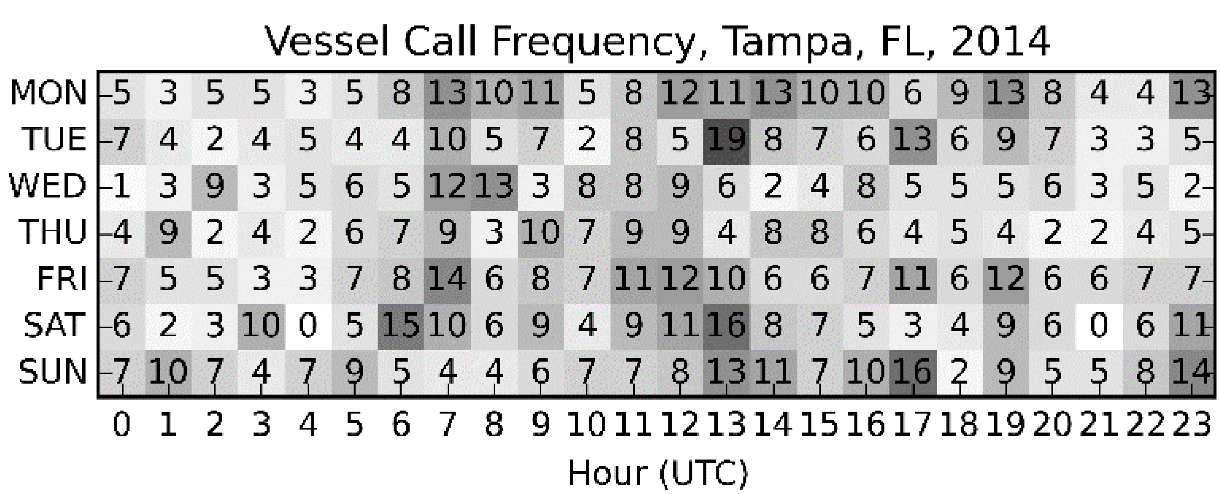
Tide Station Number: 8726384

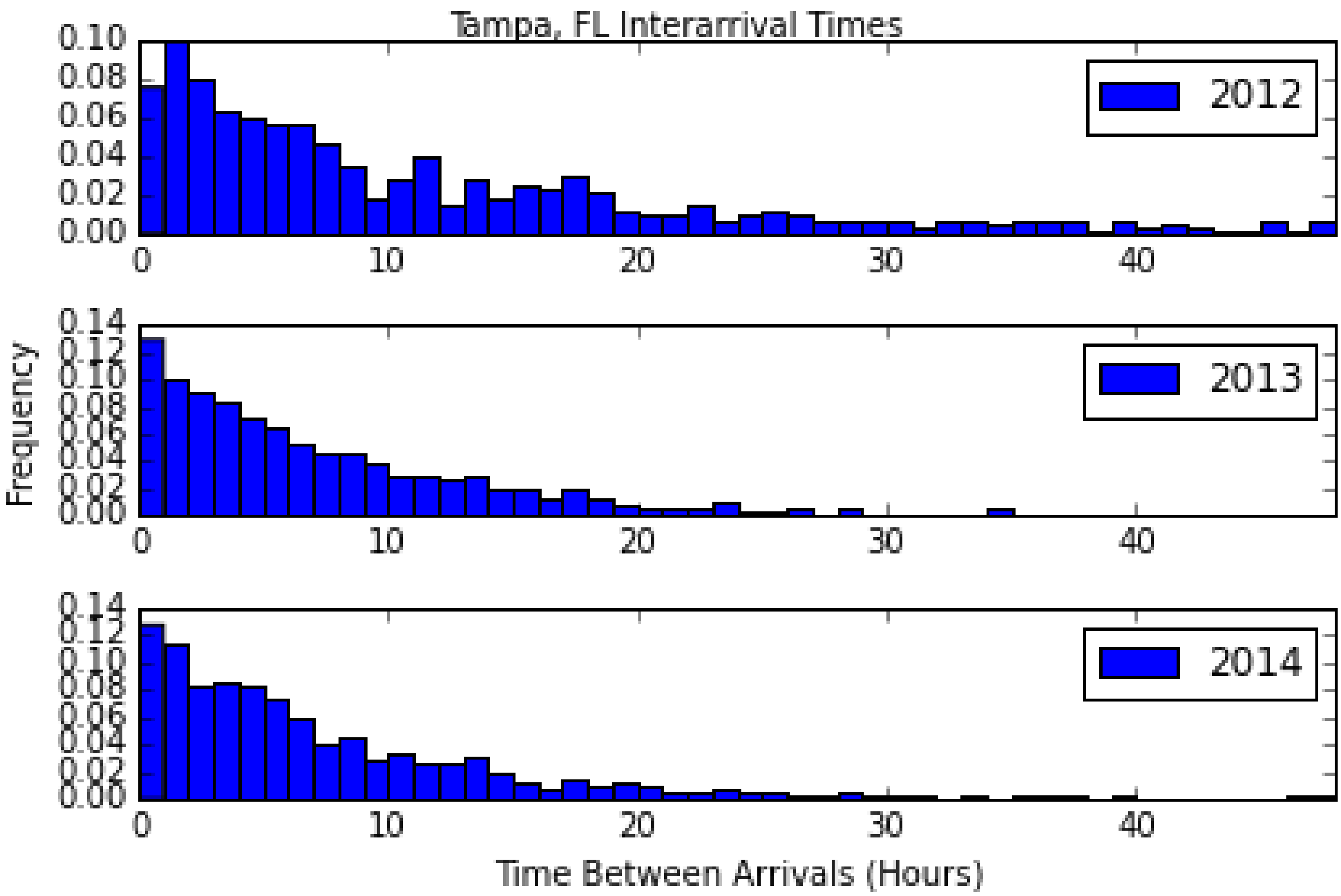
Year	Tide Range (Ft.)	Z_{25} (Ft.)	Z_{75} (Ft.)	T_{25}	T_{50}	T_{75}	TD	Arrivals
2012	3.74	0.70	1.65	0.27	0.49	0.24	-0.05	726
2013	3.78	0.71	1.64	0.25	0.52	0.23	-0.04	1150
2014	3.74	0.72	1.63	0.25	0.51	0.24	-0.02	1146



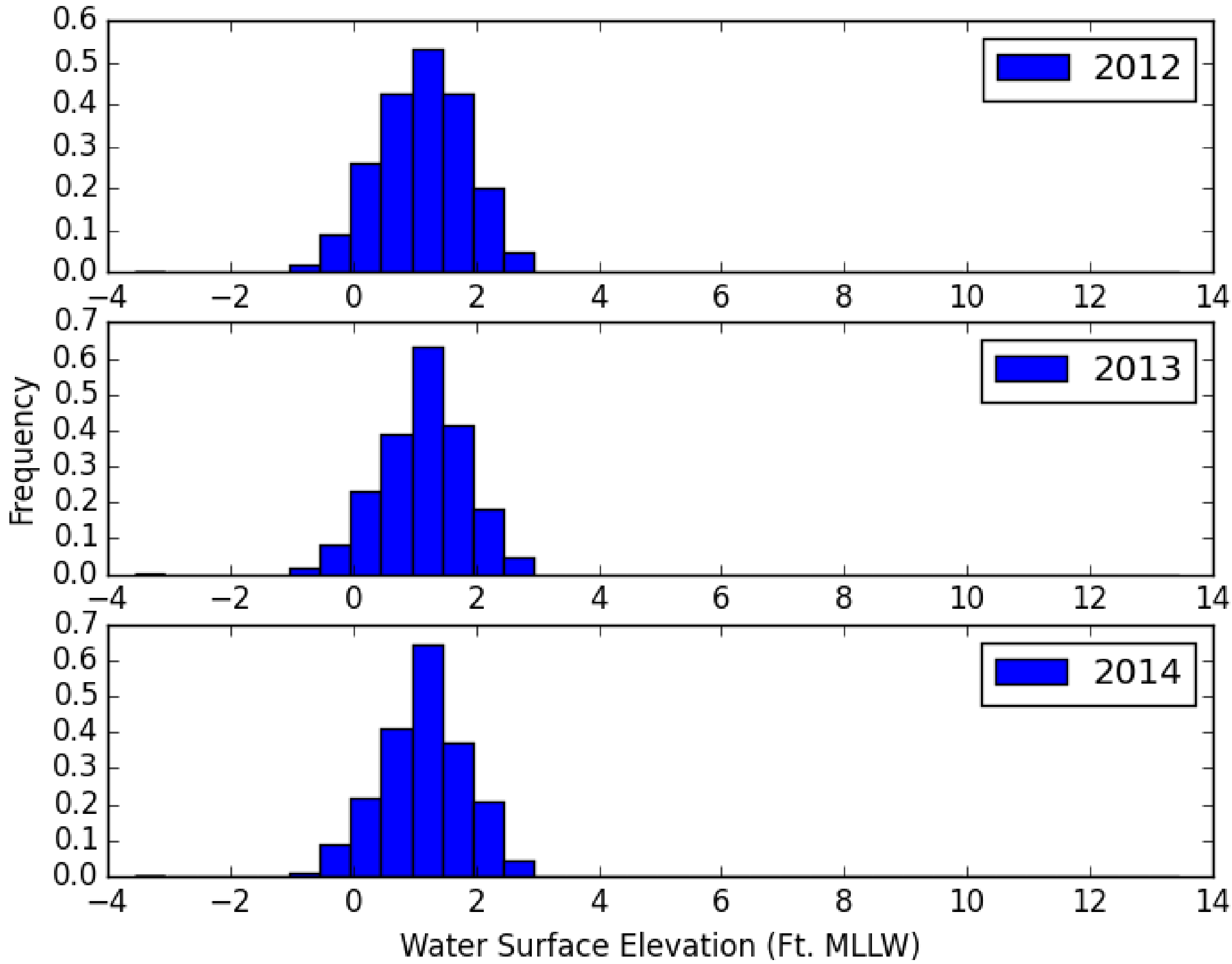

Vessel Call Frequency, Tampa, FL, 2012
MON 8 5 4 7 6 5 14 9 7 15 6 9 10 5 4 3 8 4 3 2 2 1 6 4
TUE 4 3 3 2 3 4 6 9 8 3 3 5 9 4 3 3 5 5 2 6 2 1 7 2
WED 4 1 2 1 7 3 6 5 9 3 4 7 6 3 6 3 4 4 2 4 2 3 1 2
THU 2 4 4 2 2 4 8 2 4 8 5 5 4 1 5 4 11 6 8 2 1 1 2 3
FRI 5 2 4 4 1 2 4 1 1 2 3 8 5 8 4 5 4 4 3 1 5 2 1 1
SAT 3 2 1 3 1 1 5 4 3 6 3 7 6 4 7 1 4 5 2 4 3 0 1 3
SUN 1 2 6 1 6 24 13 8 1 5 6 9 6 4 6 5 2 5 2 6 0 1 4 5
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)


Vessel Call Frequency, Tampa, FL, 2013
MON 11 5 12 10 9 9 11 11 14 6 11 6 8 10 11 9 13 2 4 7 5 2 11 12
TUE 10 4 5 4 6 7 12 6 8 6 6 6 6 7 7 8 11 10 4 4 3 6 4 8
WED 9 6 3 2 3 5 5 3 4 8 3 9 10 10 9 10 5 5 6 3 6 5 4 5
THU 7 9 7 1 6 3 2 4 2 12 10 6 10 12 12 1 4 4 4 2 3 1 7 7
FRI 6 5 3 7 1 6 12 8 4 5 7 12 12 9 6 6 5 9 7 10 7 2 4 9
SAT 9 6 7 3 3 11 12 9 12 10 9 14 10 7 11 4 4 4 13 8 7 5 9 6
SUN 8 3 8 1 3 4 5 11 4 7 7 4 13 6 5 9 10 7 4 7 10 5 2 11
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)


Vessel Call Frequency, Tampa, FL, 2014
MON 5 3 5 5 3 5 8 13 10 11 5 8 12 11 13 10 10 6 9 13 8 4 4 13
TUE 7 4 2 4 5 4 4 10 5 7 2 8 5 19 8 7 6 13 6 9 7 3 3 5
WED 1 3 9 3 5 6 5 12 13 3 8 8 9 6 2 4 8 5 5 5 6 3 5 2
THU 4 9 2 4 2 6 7 9 3 10 7 9 9 4 8 8 6 4 5 4 2 2 4 5
FRI 7 5 5 3 3 7 8 14 6 8 7 11 12 10 6 6 7 11 6 12 6 6 7 7
SAT 6 2 3 10 0 5 15 10 6 9 4 9 11 16 8 7 5 3 4 9 6 0 6 11
SUN 7 10 7 4 7 9 5 4 4 6 7 7 8 13 11 7 10 16 2 9 5 5 8 14
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour (UTC)


Tampa, FL Interarrival Times
2012
2013
2014
Frequency
Time Between Arrivals (Hours)

Tampa, FL Vessel Arrival Water Surface Elevation



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13. SUPPLEMENTARY NOTES

14. ABSTRACT

This work presents a method for extracting vessel arrival times and arrival processes from Automatic Identification System (AIS) data. This work employs the methodology presented by Mitchell and Scully (2014) for inferring tidal elevation at the time of vessel movement and calculating the tidal dependence (TD) parameter to 23 U.S. port areas for the years 2012–2014. Tidal prediction stations and observation reference lines are catalogued for considered ports. AIS data obtained from the U.S. Coast Guard, and 6-minute tide predictions, obtained from the National Oceanographic and Atmospheric Administration, are used to rank relative tidal dependence for arriving cargo and tank vessel traffic in studied locations. Results include relevant tide range and elevation threshold observations for each year and location studied. AIS-derived arrival processes, including arrival frequency, arrival rate, and interarrival time are visualized using several techniques with comparative discussion between ports to highlight implications for understanding seasonal traffic trends or port resiliency. The ports with the highest and lowest TD value, Portland, ME, and Los Angeles, CA, respectively, are discussed with regard to weekly arrival patterns and interarrival time. Cargo composition and value obtained through the Channel Portfolio Tool is also considered.

15. SUBJECT TERMS

Channels, Data processing, Dredging—Planning, Harbors, Inland navigation, Remote sensing, Ships—Automatic identification systems, Tides

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
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